BONDING STRENGTH

OF

CONCRETE AND STEEL

BY

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Armour Institute of Technology

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A Thesis Presented by

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and

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BONDING STRENGTH OF CONCRETE AND STEEL

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The increased use of reinforced concrete during the past few years has been phenomenal. Engineers as a whole have been enthusiastic in urging its use, but the public at large have become skeptical on account of the many recent failures. While these failures are, without doubt, due to improper and unskilled workmanship, rather than to poor engineering and design, it is apparent that a better knowledge of the properties of concrete, and of concrete-steel, is necessary in order that the engineer may use the same degree of accuracy in design as he does in the design of steel structures.

Concrete alone, as a building material, is nothing but rubble masonry, and rubble masonry is concrete. The only great difference between these two materials is in the contents and the methods of mixing and placing. Concrete and rubble masonry consist of two parts, the aggregate and the matrix. The former consists of the stone or gravel forming the body; the latter is the mortar that binds the individual units of the aggregate in a composite whole. In concrete the aggregate consists of gravel or crushed rock, seldom exceeding two inches in diameter, while in rubble

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masonry the aggregate is seldom smaller than six inches. The matrix of one, however, is the same as the matrix of the other: before the advent of natural and Portland cements it consisted of slacked lime and sand; now it consists of cement and sand.

The use of concrete as a building material is not new. The dome of the Pantheon, in Rome, 142 feet in diameter, was built entirely of concrete, and it stands to-day, after 2000 years. The pyramid of Nimus is formed of a single block, as was also the square stone that formed the tomb of Porsena, 30 feet wide by five feet high. In the upper floor of the House of Vestals there is a concrete slab 14 inches thick and of 20-foot span. Mexican buildings, dating back to an unknown civilization, have concrete foundations, and in the Italian colonies of Magna Graecia are evidences that the knowledge of the Greeks, in reference to concrete and its uses, was far from limited. The walls of the Reading Abbey, in England, consist of outer and inner facings of cut stone, and a core of concrete, and while the stone has crumbled into dust, the concrete core, intended to be of secondary importance only, stands to-day, a monument to the durability of concrete. At Badajos, in Spain, the walls of the castle and fortifications show the board marks of the molds. Of course the matrix of these ancient concretes was not formed of Portland cement, for this substance has been known for but eighty years, but the cementing

powers were obtained from natural cements peculiar to each locality and age.

The advent of natural and Portland cements made possible the concrete of to-day, and the ease with which iron rods and bars could be imbedded in the concrete was soon noticed and made use of. Mr. Arthur W. Buel, C.E., gives the raison d'etre of reinforced concrete as follows:[1] "The compressive resistance of concrete is about ten times its tensile resistance, while steel has about the same strength in tension as in compression. Volume for volume steel costs about fifty times as much as concrete. For the same sectional area steel will support in compression thirty times more load than concrete, and in tension three hundred times the load that concrete will carry. Therefore for duty under compression only, concrete will carry a given load at six-tenths the cost required to support it with steel. On the other hand, to support a given load by concrete in tension would cost about six times as much as to support it with steel." Concrete also offers a fire- and water-proof protection for the steel, and in some cases is used for this reason ~~is use~~ only.

The first employment of reinforced concrete is attributed to a French gardener, M. Joseph Monier, who, in 1867, or thereabouts, made pots for flowers and shrubs, of concrete,

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[1] "Reinforced Concrete," by A. W. Buel and C. S. Hill. New York: The Engineering News Publishing Co., 1906, p. 3.

and in order to reduce the thickness used metal reinforcement. M. Monier considered his invention of sufficient importance to have it patented, and while exhibiting at the Antwerp Exposition in 1879, sold the German rights to Herr G. A. Wayss. The uses to which this system were put expanded until small arches, floors, tanks, reservoirs, pipes, and similar structures were made. In the United States, Messrs. Hyatt and Ransome may be mentioned as among the pioneers of the industry. In France, M. Francois Hennebique and M. Paul Cottancin were the first to use beams of reinforced concrete.

The present time has been called the era of reinforced concrete, and to-day almost every form of engineering structure, as well as dwelling houses and industrial implements, are made of it. In almost every case, concrete takes the compressive stresses and the steel is relied upon to take those due to tension. This is particularly true in the case of beams, and in order that the steel may perform its proper functions, it is necessary that there be some union between the concrete and the steel. This union or bond may be due to three causes: (1) the adhesion of the concrete to the steel; (2) surface friction, due to the shrinkage strains set up by the concrete on setting, causing it to grip the steel firmly and generate a high frictional value; and (3) some mechanical arrangement, consisting of a deformed, twisted, or corrugated form of rod, effecting a mechanical bond between the concrete and the steel.

There is very little real adherence of concrete to clean iron. This is easily demonstrated by moulding a block or slab of concrete, and then lightly pressing a piece of square iron into the concrete with the fingers. After the concrete has set it will be found that there is little difficulty in removing the iron from the concrete. It will be noticed that in demolishing a reinforced concrte structure, the steel is easily removed if three sides are broken away. Now, if a bar of iron or steel is placed in a cement mortar, the cement will at once attack the iron or steel, provided the latter is free from dirt, oil, or grease. If the mortar be allowed to set it will be found that a chemical combination has taken place between the metal and the cement. A bright bar will become dull and will be greater in weight, and a rusty bar will become bright. It is supposed that a silicate of iron has been formed and that this compound acts as a cement between the metal and the concrete. Adhesion depends directly upon the amount of superficial area. M. Breuille states in the "Annales des Ponts et Chaussees," 7th Series, 1893, that the adhesion between the two substances is as follows:

Days	Lbs. per sq. in.	Days	Lbs. per sq. in.
2	4	16	16.2
7	9.5	22	18.5
12	13.5	27	18.8

It will be seen from the above that very little of the bond is due to this chemical reaction, and it follows,

therefore, that the greater part is due to the "grip" which the concrete exerts upon the steel in setting. If concrete sets in air it contracts, and if it is under water while setting it expands, from which it follows that reinforced concrete should never be allowed to set under water, if any reliance is to be placed upon the bond between the concrete and the steel.

Herr Bauschinger and M. de Joly from a series of experiments concluded that the bond of concrete and iron or steel rods was from 570 to 710 pounds per square inch of surface. These results are, perhaps, those most widely quoted. MM. Coignet and Tedesco made experiments on round rods from .63 to 1.3 inches in diameter, and obtained values of from 285 to 355 pounds per square inch of surface, but concluded that much larger values could be used in calculations with safety.

M. de Joly in further experiments found that the slipping point occurred soon after the elastic limit of the steel was reached, and concluded that the bond did not vary as the superficial area, but as the sectional area, and slippage did not take place until after the sectional area of the steel had been reduced. He further states that a layer of cement is generally found on the rods after being drawn out, pointing to the probability of failure being due to the shearing of the concrete itself. He also found that the form of the bar had much to do with the bonding strength, on account of the expansion and contraction of the concrete

while setting, causing a tendency to disunion. He summarized his results as follows:

1. The bonding strength varied at different points along the length of the rod.
2. It is greater with a rough then with a smooth surface.
3. It increased with the proportion of cement up to a certain limit.
4. It varied very slightly with the quality of slow-setting Portland cement.
5. It increased somewhat with the fineness of grinding.
6. It was less with quick-setting than with slow-setting Portland cement.
7. It was very variable for slag cements.
8. It increased for mortars with the size of the sand grains up to a certain point.
9. It was less for concrete than for mortars.
10. It increased rapidly with the proportion of water used for mixing, and reached its maximum for a somewhat sloppy concrete, the consistency of which was wetter than that which gives the maximum resistance to compressive stresses.
11. It increased with the age of the concrete.

Professor Hatt, with 7/16 inch and 5/8 inch rods, imbedded 6 and 6.4 inches in 1:2:4 concrete, obtained, after 34 days, from 470 to 735 (average 636) pounds per square inch for the first, and from 714 to 780 (average 756) pounds per square inch for the latter. He remarks that the sliding friction after the first movement was from 60 to 70 per cent. of the bonding strength.

M. Considere found 256 pounds per square inch as the value of the bond between concrete and steel. Messrs. Sam W. Emerson and George A. Peabody, at Case School of Applied Sciences, found that the bond varied from 444 to 564 (average 516) pounds per square inch for 1:3:6 concrete. They also state that the richness of the concrete has but little

effect upon the bond, and that the bond of mortar is less than concrete. The results of their tests also show that the age of the concrete has little or no effect upon the bonding strength.

Experiments at the Massachusetts Institute of Technology under the direction of Professor Charles M. Spofford, gave the results upon the bond between steel and 1:3:6 concrete, age one month, as follows:

3/4-inch round rods, 219 to 271 lbs. per sq. in.
3/4-inch square rods, 221 to 274 lbs. per sq. in.
Flat bars somewhat smaller results.
Patented bars, imbedded 12 in., 454 to 508 lbs. per sq. in.
Patented bars, imbedded 16 in., 228 to 410 lbs. per sq. in.
Patented bars, imbedded 26 in., 223 to 298 lbs. per sq. in.

In all cases where patented bars were used the blocks either split or the bars broke.

From tests made at Columbia University, in 1903, it was found:

Plain rusted, 1 month, 437; 3 months, 642 lbs. per sq. in.
Plain clean, 1 month, 294; 3 months, 431 lbs. per sq. in.
Twisted, 410 to 788.

Where twisted bars were used the blocks split in all cases.

The reader has probably noted the great discrepancy in the results of the tests that have been made to determine the value of the bond existing between the concrete and steel. This is especially prominent in the case of plain, smooth rods. It seems that the value of the bond depends upon nearly all the varying functions of the concrete and steel, it being greater for rusty bars than for clean, greater for

clean than for oily, etc. It varies with the proportioning of the concrete, with its age , and with its consistency, and depends upon whether the concrete set in air or in water, and whether the climatic conditions were such as to cause alternate contractions or expansions or not. As a result of this wide variation in results, various authorities have concluded that 50 pounds per square inch is the greatest safe value that can be used, and that the bar should be imbedded at least 80 times its diameter. Of course, this depth will vary with the size of the rod, and if we use 50 pounds per square inch of superficial area as the safe bond between the concrete and the steel, and 16,000 pounds per square inch of sectional area as the safe stress in the steel, then

$$50\pi dl = 4000\pi d^2,$$

therefore

$$l = 80d.$$

That is to say, the steel should be imbedded in the concrete at least 80 times its diameter.

In order that the uncertainty of the bond between the concrete and the steel might not exist, many bars have been invented that give a mechanical bond with the concrete. In this case the bond is unlimited, and failure will take place only by the shearing of the concrete, or the failure of the concrete by tension, the discussion of which will be taken up later. This also allows the bar to be painted

or oiled, in order to prevent rust, without interfering with the bond.

Among the many patented bars on the market to-day might be mentioned the Ransome twisted bars, which are usually twisted cold on the site of the work; the Johnson corrugated bars, which are square and have corrugations on all four sides; the Thatcher rolled bar, which is round, but flattened at regular intervals; the Thatcher riveted bar, which is a strip of structural steel, with staggered rivets at regular intervals; and the Kahn cup bar, which is round, with four projecting webs ninety degrees apart, and diaphragms between these webs forming cups on the surface of the round rod.

In some tests made at Lewis Institute in 1906 by Professor DePuy, for Mr. T. L. Condron, and reported in a paper read before the Wester Society of Engineers, notice was taken for the first time of the amount of slip and the ratio between the stress in the steel and the slip. The investigations which have been made by the authors have been along this line, as well as along the lines previously followed. The object of the tests made was to find the ultimate bonding strength of different kinds of bars, and also to find the point at which the bar first yielded.

After careful investigation, it was decided that 1:3:6 concrete would be used, on account of the fact that it is the most widely used mixture for reinforced concrete work. The size chosen for the blocks was 6"x 6"x 12". It was thought best to confine the test to one depth of imbedding

and to make that depth of such an amount that there would be no possibility of the steel breaking before the ultimate strength of the bond had been reached. The blocks were made 6"x 6" in plan, as this size offered sufficient area in compression. No doubt, if larger blocks had been used, the value of the bonding stress developed by the twisted and cup bars would have been much higher, but bars are spaced much closer than six inches in practice, and the results derived from such tests might be misleading. The values which may be obtained for these deformed bars are limited only by the size of the block, the shearing value of the concrete, and the strength of the steel.

The concrete was made of Universal Portland cement, No. 5 washed gravel, and unsieved torpedo sand, in the ratio of one part cement, three parts sand, and six parts gravel, by volume. The cement was tested, and found to satisfy the specifications of the American Society for Testing Materials, developing a tensile stress of 720 pounds per square inch for an average of six neat briquettes, one day in air and six days in water. The sand contained 34 per cent., and the gravel 38 per cent., voids. Both were clean and free from dirt.

The molds were made to order for these tests, being 25 in number. Dimensional drawings for them are shown on Plate I. Some trouble was caused by the warping of the sides, but the blocks cast were of the uniform depth of

12 inches. The bars were held in place by strips of steel placed accross the tops of the molds. The strips had holes, of the same diameter as that of the bars, drilled in them, as well as a small one toward each end, through which nails fastened the strips to the sides of the molds. These strips are shown on Plate I. The bars were placed in holes drilled in the middle of the bottom of the molds of such depth that the bars extended about one-quarter inch above the block when molded.

The concrete for each test was mixed on separate days, but great care was taken to have all the conditions the same. The cement and the sand were mixed dry until no change in color could be distinguished and to this was added sufficient water to make a plastic mortar. The gravel was then added, and the whole mixed to such consistency that the water flushed to the surface when tamped. The concrete was well tamped in layers while being placed.

After about one week, the forms were removed. During the first week the concrete stood in a room whose temperature averaged about 80 degrees, and for the rest of the time in a place exposed on one side to the weather of February, March and April, about two weeks of which were below freezing.

Six different bars were used: 1/2-inch and 3/4-inch plain round bars; 1/2-inch and 3/4-inch twisted bars; and 1/2-inch and 3/4-inch cup bars. The round and cup bars

were oiled by the manufacturers to prevent rust, but the twisted bars were rusty. Tests were made at the end of 30 days, 61 days, and 91 days, four specimens being tested in most cases, although the results from several were discarded.

Plates II, III, and IV show the apparatus used for the tests, In Plate II, A is the frame of the machine, D the draw-head, and C the concrete block with the bar K imbedded in it. The steel plate E was covered with several layers of asbestos M, so that the concrete would have even bearing. A micrometer, taken from an extensometer, was mounted at F in such a manner as to make contact with the bar. Connected to the micrometer and to the frame of the machine was an electric circuit, arranged in such a manner through the relay R that when the circuit was broken the bell B would ring. In this manner any slip in the concrete could be instantly detected and noted. The switch S was used to prevent the ringing of the bell while changing specimens.

Mr. T. L. Condron, in his paper before the Western Society of Engineers[1], says: "A series of tests were made at the U. S. Testing Laboratory at the Watertown Arsenal recently to determine the 'adhesion resistance of steel bars in cement and mortar prisms.' In the report it is

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[1] Journal of the Western Society of Engineers, Vol. XII, No. 1. February, 1907.

stated, 'concrete prisms were secured in the jaws of the testing machine between V-shaped wooden cushions, against which a sufficient compressive force was applied to hold the specimens in place against the tensile pull of the bars.' The report goes on to say, 'this lateral pressure in the sides of the prisms prevented their splitting lengthwise during the tests and in some degree probably resulted in applying pressure against the sides of the bars.' "
It will at once be seen that the results obtained in those test are higher than would be attained in practice. The pressure exerted against the side of the bars would, without doubt, increase the bond of the metal and concrete, while the prevention of the splitting of the blocks causes the characteristic action of patented bars to be lost.
The method adopted by the authors is one that more nearly duplicates conditions in practice.

Results and Observations

Sixty-nine specimens were tested in all, but the results of six were of such a character as to warrant discarding the results obtained from them. As a result, record has been made of but sixty-three specimens.

In the test of each specimen, the load at which first slip took place was noted. The accuracy of the apparatus was such that the magnitude of this slip was about 1/1000 of an inch. It was impossible to learn at what load slipping actually started, but the load at which the bar had slipped in the neighborhood of 1/1000 of an inch could be noted, and this load is called the load of first slip. Expressed in pounds per square inch of superficial area, the average of the tests of each kind of bar are as follows:

	30 days	61 days	91 days
1/2-inch round...........	154	176	194
1/2-inch twisted.........	150	208	333
1/2-inch cup.............	195	215	214
3/4-inch round...........	208	205	265
3/4-inch twisted.........	121	208	196
3/4-inch cup.............	201	233	214

In the case of the twisted and cup bars, the superficial area was taken to be that of a square bar of the same dimension. While this is not exactly correct, it serves as a means of comparing these bars with others.

It will be seen that the strength of the bond of the 1/2-inch round bars increased with the age of the

concrete; the bond of the 3/4-inch round bars is slightly less at 61 days than at 30 days, but greater at 91 days than at either 30 or 61 days. It will also be noted that the load at which slip first took place for the 1/2-inch round bars is less than for the 3/4-inch bars---the loads are almost proportional to the diameters, which would seem to support the theory advanced by M. de Joly that the bond, being due to the stress set up in the steel by the contraction of the concrete while setting, varies as the sectional area instead of the superficial area. It will be shown later that this is the case only for the plain bars, and not for the patented ones.

The load at which slip first took place for the 1/2-inch twisted bars increased with the age of the concrete, while for the 3/4-inch twisted bars the load is greater at 61 days than at either 30 days or 91 days, and greater at 91 days than at 30 days. In these rods the load per square inch of superficial area is less for the 3/4-inch bars than for the 1/2-inch bars. This is possibly due to the fact that the 3/4-inch bars have fewer twists to the foot than the 1/2-inch bars, and therefore the angle which the surface of the bar makes with its axis is less.

For the 1/2-inch cup bars, the load is greater at 61 days than at 30 days, and about the same as at 91 days. For the 3/4-inch cup bars, the load is greatest

at 61 days and least at 30 days. For each age of the concrete, the bond of the 1/2-inch bars is about the same as for the 3/4-inch bars, showing that the bond varies as the superficial area of the bar.

An examination of the table on the preceding page shows that the first slip of the twisted bars occurred with a less load than is required for either the round or the cup bars, and that the round bars require less load than the cup bars. The latter is to be expected, but the former comes as a surprise, as the object of twisting the bar is to enable it to take greater stress.

After noting the load at which first slip occurred, further load was applied to each specimen, and the slip for each load was noted. The results have been tabulated and may be found in the appendix to this report. Curves have also been plotted, with the total load as ordinates and the slip in 1/100 of an inch as abscissae. An examination of the tables and curve sheets will show that in the case of the round rods the maximum load occurred at or near the point where first slip was noted, and beyond this point the rod could be pulled through the concrete with a decreasing load. In the case of the twisted and cup bars, in order that further slip might take place, it was necessary to apply additional load, and this load was increased until the blocks split. It will be seen from the curve sheets that the form of the load-slip curves

of the patented bars are parabolas; i. e., the slip is proportional to the square of the load.

The average of the loads necessary to produce the same slip, for each style of bar and age of concrete, have been computed from values taken from the curves, and the loads reduced to pounds per square inch of superficial area. The results of these operations are shown in Tables II to X, and from these tables curves have been plotted showing the relations between the three kinds of bars of the same dimensions and the same age, and others showing the effect of age upon the load-slip curve of each bar. These curves accompany the report as Plates VI to XVII. It will be noted that in every case the curves of the cup bars are very much steeper than those of the twisted bars, and that, on the average, the twisted bars slipped about five times as far as did the cup bars before the concrete blocks split.

In Table I the results of all the tests have been summarized, and the maximum bond in pounds per square inch of superficial area have been calculated. It will be seen that a 1/2-inch cup bar gives the greatest result (660 pounds per square inch) and that a 1/2-inch round bar gives the smallest (93 pounds per square inch). The averages of the maximum bonds may be found in Tables II to X, but for the sake of convenience they are given in the following table in pounds per square inch:

	30 days	61 days	91 days
1/2-inch round....................	154	191	202
1/2-inch twisted..................	275	302	504
1/2-inch cup......................	340	395	504
3/4-inch round....................	239	209	300
3/4-inch twisted..................	215	263	249
3/4-inch cup......................	290	308	314

The above table shows that the maximum bond of all the 1/2-inch bars and the 3/4-inch cup bars increases with the age of the concrete. For the 3/4-inch round bar the bond is greatest at 91 days and least at 61 days. In the case of the 3/4-inch twisted bars, the bond is least at 30 days and greatest at 61 days.

The observations given on the load at which slip first occurrs may be applied to the maximum bond of the round bars; viz., that the bond varies as the sectional area instead of the superficial area of the rod. For the twisted and cup bars the maximum bond in pounds per square inch is less for the 3/4-inch than for the 1/2-inch bars. This is due to the fact that the concrete blocks split in every case, and as this splitting is due to the wedging action of the ~~bar~~ projections on the bars, it depends upon the total load upon the bar and not upon its superficial or sectional area. In other words, if the results of these tests may be depended upon, an inch bar cannot be relied upon to take more stress than a 1/2-inch bar, if the bars are spaced closer together than a pre-determined distance, this distance being of such magnitude that the concrete will develop in tension sufficient resistance

to overcome the bursting action of the bar, acting as a wedge.

The effect of this bursting action may be approximately investigated. A simple case will be assumed. Suppose that A, Fig. 1, is a section of a circular wedge, or cone, acting on the plate B. Then, if a load P be applied to A, it may be considered replaced by two forces, each P/2, acting at C and D. Now, the load P will cause normal reactions NN against the face of the wedge, each equal to $P/(2 \cos \phi)$, and the horizontal components of these reactions must be resisted by equal and opposite horizontal forces, each equal to $(P \tan \phi)/2$.

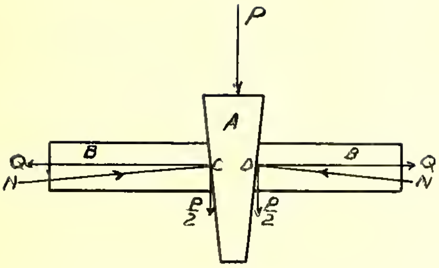

Fig. 1.

An infinite number of these sections may be taken through the wedge with the same results.

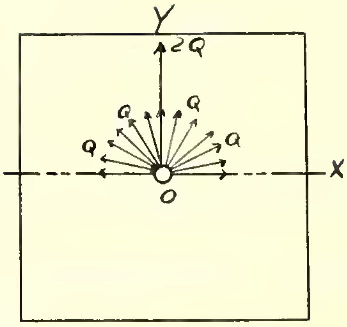

Fig. 2.

If the plate was viewed in plan it would be as in Fig. 2, with an infinite number of forces, each equal to $Q = (P \tan \phi)/2$, acting radially to the center of the wedge. Suppose it is required to find the force tending to cause rupture along the section XX. It is evident that the components of the forces parallel to the axis of X

balance each other, and it remains to find the sum of the components parallel to the axis of Y for one-half of the wedge. If θ be the angle which one of the forces makes with the axis of X, then $Q \sin \theta$ is the magnitude of the component parallel to the axis of Y, and $\int (Q \sin \theta) d\theta$ is the sum of these components, the limits of integration being 0 and π. Evaluating the above integral we have

$$\int_0^{\pi} (Q \sin \theta) d\theta = 2Q$$

and the magnitude of this bursting force is then $P \tan \phi$.

This force will at at the center of the plate B, and the distribution of this stress accross the plate is somewhat complicated. It will have a maximum value at the edge near the wedge, and will have a value at a contiguous section equal to this maximum value less the change in shear caused by the deformation of the material. This change in shear will depend upon the modulus of elasticity of the material, and in the case of concrete it will be very small. The unit stress at the edge, then, will be slightly less than at the center. This distribution of

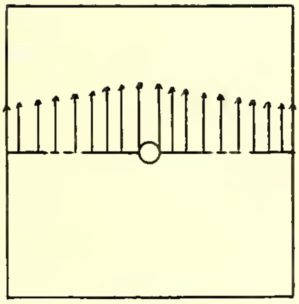
Fig. 3.

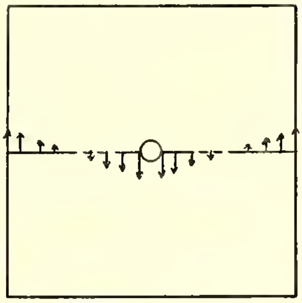
Fig. 4.

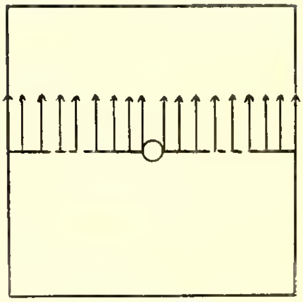
Fig. 5.

stress is shown in Fig. 3. There is also a cantilever action due to the force 2Q acting parallel to the section. This will cause a tension in the outer half and a compression in the inner half of the part considered as a beam. The distribution of stress due to this action is shown in Fig. 4. Fig. 5 shows the addition of the stresses due to both couses, and if the distance OX is not too great, a fairly uniform distribution of stress results.

Now suppose that the bars are spaced a inches apart and that the diameter of the bars is b inches, then the area of the concrete to resist the bursting force is $d(a - b)$, where d is the depth the bar is imbedded. If f is the unit strength of concrete in tension, then $fd(a - b)$ is the magnitude of the resistance of the total area of the concrete, which must equal $P \tan \phi$. That is

$$fd(a - b) = P \tan \phi .$$

Also, if F is the unit tensile strength of the steel, and k is some constant depending upon the shape of the transverse cross-section of the bar, such that kb^2 is the area of the bar, then

$$P = Fkb^2,$$

and

$$fd(a - b) = Fkb^2 \tan \phi .$$

Therefore

$$b = \frac{-f \pm \sqrt{f^2d^2 + 4Fkda \tan \phi}}{2Fk \tan \phi} .$$

Also, solving for a, if b is pre-determined or assumed,

$$a = \frac{Fkb^2 \tan \phi}{fd} + b.$$

For substitution in the above formulae, the angle ϕ must necessarily be determined by observation.

The results show that the cup bar is the better of the two patented bars, as it gives greater maximum bond in most cases, gives greater values in all cases for the point of first slip, and gives less slip for a corresponding load. The 3/4-inch round rods give higher results than the 3/4-inch patented bars. This, of course, depends upon the width of the blocks in which the bars are imbedded, but not upon the depth.

The results found by the authors are low, compared with some of the results enumerated on previous pages. The following table has been prepared, from which comparisons can be easily made, the values being in pounds per square inch of superficial area and for plain round bars:

Zeitschrift des Vereins Deutcher Ingenieure (Vol. 49, '05) Cement Age, Oct., 1905.............	83 to 592
E. Morsh (From Beton und Eisen, 1903)...........	100 to 696
E. S. Wheeler, U. S. Assistant Engineer..........	111 to 556
Webb and Wilsey, Armour Institute of Technology..	154 to 263
Prof. A. N. Talbot, University of Illinois.......	174 to 386
Prof. C. E. DePuy, Lewis Institute..............	138 to 341
Prof. C. W. Spofford, Mass. Inst. of Technology..	219 to 374
M. Considere....................................	256
S. W. Emerson, Case School of Applied Sciences...	278 to 587
Prof. F. H. Constant, University of Minnesota....	316 to 854
Prof W. K. Hatt, Purdue University...............	470 to 756
Prof. Bauschinger................................	570 to 640

It may be that the results found by the authors are low on account of the fact that the round and cup bars were oiled by the manufactures to prevent rust. The weather

may also have had some influence upon the "grip" of the concrete.

After destruction of the blocks, the bars were examined and found to have thin coatings of cement on them. It appeared that the cup bars sheared the concrete for a small distance in several specimens, but in no case could such phenomena be noted for the twisted bars.

Tests were made of the steel to determine the elastic limit, ultimate strength, and per cent. elongation in eight inches, with the following results:

	Elas. Limit lbs. / sq. in.	Ult. Strength lbs. / sq. in.	o/o Elong.
1/2-inch round...........	53560	81000	15.5
1/2-inch twisted.........	78400	89400	9.95
1/2-inch cup.............	70000	78800	7.5
3/4-inch round............	66230	107000	11.2
3/4-inch twisted.........	64000	77200	10.7
3/4-inch cup.............	58760	95000	10.4

In every test has been recorded the ratio of the stress in the bar to the elastic limit and in no case was this ratio greater than unity. This shows, then, that the bars did not slip on account of the contraction of area due to stressing the bars beyond their elastic limit.

Taken as a whole, the results of these tests show that patented bars cannot be depended upon to take any more stress, on account of their supposed greater bond, than plain bars, for ordinary spacing of the bars; that if patented bars are not stressed beyond the elastic limit, a large bar will not carry a much greater load than one which is just stressed to the elastic limit, if

reliance is placed upon the bond between concrete and steel to transfer the load; that the load which twisted bars will carry depends upon the number of turns per foot, because the greater the number of turns the less the value of tan ϕ in the formulae on page 22; that the bond increases with the age of the concrete, but not according to any definite law; that cup bars have a greater bonding strength than twisted bars; that cup bars will cause failure in a manner more sudden that the twisted bars, on account of the fact that less slip occurrs before failure; and that plain bars should not be stressed to such a point that there is the least slip between the concrete and the steel.

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The Inland Steel Co., who furnished the plain bars.

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Mr. W. F. Deitzch, of the Mechanical Engineering Department of Armour Institute, for the use of the cement and testing laboratories.

Prof. A. E. Philips, of the Civil Engineering Department of Armour Institute, for advice and assistance.

Prof. M. B. Wells, of the Civil Engineering Department of Armour Institute, for advice and assistance.

Table I

Results of Tests of Bond of Steel and Concrete.

Thesis of A.R. Webb and G.H. Wilsey.

Test No.	Size of Bar.	Style of Bar	Age days.	Elongation Inches.	Max. Load lbs.	Max. Bond lbs. per □"	Max. Stress lbs per □"	Ratio Stress To Elastic Limit.
1	1/2	Round	30	.0053	3890	206.4	19810	.3699
2	1/2	"	30	.0018	1750	92.8	8910	.1662
3	1/2	"	30	.0034	3180	168.7	16190	.3026
4	1/2	Twisted	30	.1169	8420	350.9	33680	.4296
5	1/2	"	30	.0786	6330	263.8	25320	.3230
6	1/2	"	30	.0607	6710	279.6	26840	.3423
7	1/2	Cup	30	.0231	7260	302.5	29040	.4149
8	1/2	"	30	.0141	8780	365.8	35120	.5017
9	1/2	"	30	.0056	7040	293.4	28160	.4023
10	3/4	Round	30	.0202	3710	131.2	8397	.1268
11	3/4	"	30	.0028	6200	219.4	14030	.2118
12	3/4	"	30	.0081	5800	205.2	13130	.1982
13	3/4	"	30	.0071	5510	194.9	12470	.1883
14	3/4	Twisted	30	.0755	7100	197.2	12620	.1972
15	3/4	"	30	.0863	8180	227.2	14540	.2272
16	3/4	"	30	.0985	7240	201.1	12870	.2011
17	3/4	"	30	.0810	9120	253.3	16210	.2533
18	3/4	Cup	30	.0090	10430	289.7	18550	.3157
19	3/4	"	30	.0305	11610	322.5	20620	.3509
20	3/4	"	30	.0108	8160	226.7	14490	.2467
21	3/4	"	30	.0107	11690	324.7	20760	.3535
22	1/2	Round	61	.0076	3470	184.1	17670	.3299
23	1/2	"	61	.0012	3670	194.7	18690	.3490
24	1/2	"	61	.0026	4710	249.9	23980	.4477
25	1/2	"	61	.0017	2800	148.5	14260	.2662
26	1/2	Twisted	61	.0396	8210	342.1	32840	.4189
27	1/2	"	61	.0739	8660	360.8	34640	.4418
28	1/2	"	61	.0087	7360	306.8	29440	.3755
29	1/2	"	61	.0659	7390	307.9	29560	.3770
30	1/2	Cup	61	.0749	6680	278.4	26720	.3817
31	1/2	"	61	.0646	11200	466.7	44800	.6400
32	1/2	"	61	.0222	9730	405.4	38920	.5560
33	1/2	"	61	.0436	9740	405.8	38960	.5565
34	3/4	Round	61	.0019	4290	151.8	9710	.1466
35	3/4	"	61	.0016	6200	219.4	14030	.2118
36	3/4	"	61	.0116	7850	277.7	17770	.2683
37	3/4	"	61	.0036	6000	212.3	13580	.2050
38	3/4	Twisted	61	.0013	10990	305.6	19540	.3053
39	3/4	"	61	.0085	10240	284.5	18200	.2844
40	3/4	"	61	.0687	8000	222.2	14220	.2222
41	3/4	"	61	.0538	11170	310.3	19860	.3103
42	3/4	Cup	61	.0024	4330	120.3	7690	.1309
43	3/4	"	61	.0085	12720	353.4	22590	.3845
44	3/4	"	61	.0135	9450	262.5	16780	.2856
45	3/4	"	61	.0130	11760	326.7	20890	.3555
46	1/2	Round	91	.0015	2660	141.1	13550	.2530
47	1/2	"	91	.0031	3440	182.5	17520	.3267
48	1/2	"	91	.0066	5470	290.2	27850	.5200
49	1/2	Twisted	91	.0813	12150	506.3	48600	.6199
50	1/2	"	91	.1699	14770	615.5	59080	.7536
51	1/2	"	91	.0995	9600	400.0	38400	.4898
52	1/2	Cup	91	.0770	12520	521.3	50080	.7154
53	1/2	"	91	.0364	15860	660.9	63440	.9063
54	1/2	"	91	.0837	12120	505.0	48480	.6926
55	3/4	Round	91	.0049	9190	325.1	20800	.3140
56	3/4	"	91	.0048	7050	249.4	15960	.2410
57	3/4	"	91	.0041	9110	322.3	20640	.3116
58	3/4	Twisted	91	.0831	11660	323.9	20730	.3239
59	3/4	"	91	.0351	7250	201.4	12890	.2014
60	3/4	"	91	.0980	9220	256.1	16390	.2561
61	3/4	Cup	91	.0098	8670	240.8	15400	.2621
62	3/4	"	91	.0113	12110	336.4	21510	.3661
63	3/4	"	91	.0059	13540	376.1	24050	.4093

TEST OF BOND
Between
STEEL AND CONCRETE

TEST A				TEST B			
Elongation in Inches.	Load in lbs.	Bond lbs per □"	Stress in Steel lbs per □"	Elongation in Inches.	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs per □"
0	2920			0	3600	150.0	14400
.005	2896	153.6	14740	01	4200	175.0	16800
.01	2786	147.8	14180	02	4900	204.2	19600
.02	2533	135.4	12900	03	5350	222.9	21400
.03	2333	123.8	11880	04	5750	239.6	23000
.04	2196	113.8	10930	05	6100	254.2	24400
.05	2053	108.9	10450	06	6400	266.7	25600
.06	1920	101.9	9770	07	6600	275.0	26400
.07	1800	95.5	9160				
.08	1670	88.4	8520				
.09	1580	83.8	8040				
.10	1510	79.9	7670				
.11	1410	75.0	7200				
.12	1340	71.1	6820				

Test	A	B
Age of Concrete, days	30	30
Style of Bar	Round	Twisted
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	1.57	2.00
Total Bonding Area, sq. ins.	18.85	24.00
Maximum Load, lbs.	2920	6600
Maximum Bond, lbs. per sq. in.	155.0	275.0
Area of Steel, sq. ins.	.1964	.25
Stress in Steel, lbs. per sq. in.	14840	26400
Elastic Limit, lbs. per sq. in.	53560	78400
Ratio of Stress to Elastic Limit	.2771	.3567

Test of Bond
between
Steel and Concrete.

TEST C				TEST D			
Elongation in Inches.	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"	Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"
0	4670	194.6	18680	0	5870	207.7	13290
.002	6000	250.0	24000	.01	6750	238.8	15280
.004	6200	258.3	24800	.02	6180	218.6	13990
.006	6900	287.5	27600	.03	5980	217.6	13590
.008	7150	297.9	28600	.04	5160	182.6	11680
.010	7300	304.2	29200	.05	4750	168.1	10750
.012	8120	338.3	32480	.06	4400	155.7	9960
.014	8170	340.4	32680				

Test	C	D
Age of Concrete, days	30	30
Style of Bar	Cup	Round
Size of Bar, ins.	1/2	3/4
Bonding Area per linear inch, sq. in.	2.00	2.356
Total Bonding Area, sq. ins.	24.00	28.274
Maximum Load, lbs.	8170	6750
Maximum Bond, lbs. per sq. in.	340.4	238.8
Area of Steel, sq. ins.	.25	.4418
Stress in Steel, lbs. per sq. in.	32680	15280
Elastic Limit, lbs. per sq. in.	70000	66230
Ratio Stress to Elastic Limit	.4954	.2307

TEST OF BOND
Between
STEEL AND CONCRETE.

TEST E				TEST F			
Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"	Elongation in Inches.	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"
0	4350	120.8	7730	0	7250	201.4	12890
.01	4825	134.0	8580	.0025	9225	256.3	16400
.02	5250	145.9	9330	.0050	10075	279.9	17910
.03	5700	158.3	10130	.0075	10390	288.6	18470
.04	6250	173.6	11110	.0100	10425	289.6	18540
.05	6675	185.4	11870				
.06	7100	197.2	12620				
.07	7500	208.4	13330				
.08	7750	215.3	13780				

Test	E	F
Age of Concrete, days	30	30
Style of Bar	Twisted	Cup
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	7750	10425
Maximum Bond, lbs. per sq. in.	215.3	289.6
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	13780	18540
Elastic Limit, lbs. per sq. in.	64000	58760
Ratio Stress to Elastic Limit	.2153	.3155

Table V

TEST OF BOND
Between
STEEL AND CONCRETE.

TEST G				TEST H			
Elongation in Inches.	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"	Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"
0	3325	176.4	16930	0	5000	208.3	20000
.005	3590	190.5	18180	.0025	6000	250.0	24000
.010	3500	185.7	17820	.0050	6200	258.3	24800
.015	3340	177.2	17000	.0100	6350	264.6	25400
.020	3180	168.7	16190	.0200	6600	275.0	26400
.025	2925	155.2	14890	.0300	6880	286.7	27500
.030	2690	142.7	13700	.0400	7250	302.1	29000

Test	G	H
Age of Concrete, days.	61	61
Style of Bar	Round	Twisted
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	1.57	2.00
Total Bonding Area, sq. ins.	18.85	24.00
Maximum Load, lbs.	3590	7250
Maximum Bond, lbs. per sq. in.	190.5	302.1
Area of Steel, sq. ins.	.1964	.25
Stress in Steel, lbs. per sq. in.	18180	29000
Elastic Limit, lbs. per sq. in.	53560	78400
Ratio Stress to Elastic Limit	.3395	.3919

Table VI

TEST OF BOND
Between
STEEL AND CONCRETE

TEST I				TEST J			
Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"	Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"
0	5150	214.6	20500	0	5800	205.1	13130
.0025	6560	273.3	26240	.0025	5900	208.6	13360
.005	7900	329.2	31600	.005	5900	208.6	13360
.0075	8670	361.3	34680	.01	5625	199.0	12740
.01	8900	370.8	35600	.02	5000	176.8	11320
.02	9480	395.0	37920	.03	4550	160.9	10300

Test	I	J
Age of Concrete, days	61	61
Style of Bar	Cup	Round
Size of Bar, ins.	1/2	3/4
Bonding Area per linear inch, sq. ins.	2.00	2.356
Total Bonding Area, sq. ins.	24.00	28.274
Maximum Load, lbs.	9480	5900
Maximum Bond, lbs per sq. in.	395.0	208.6
Area of Steel, sq. ins.	.25	.4418
Stress in Steel, lbs. per sq. in.	37920	13360
Elastic Limit, lbs. per sq. in.	70000	66230
Ratio of Stress to Elastic Limit	.5419	.2017

Table VII

TEST OF BOND
Between
STEEL AND CONCRETE

TEST K				TEST L			
Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"	Elongation in Inches	Load in lbs.	Bond lbs per □"	Stress in Steel lbs. per □"
0	7500	208.3	13330	0	8400	233.3	14930
.005	7675	213.2	13640	.0005	9100	252.8	16180
.01	8025	223.0	14270	.001	10100	280.6	17960
.02	8675	241.0	15420	.002	10300	286.1	18310
.03	9050	251.4	16090	.003	10500	291.7	18670
.04	9225	256.3	16400	.004	10650	295.8	18930
.05	9450	262.5	16800	.005	10800	300.0	19200
				.006	10950	304.2	19470
				.007	11100	308.4	19740

Test	K	L
Age of Concrete, days	61	61
Style of Bar	Twisted	Cup
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	9450	11100
Maximum Bond, lbs. per sq. in.	262.5	308.4
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	16800	19740
Elastic Limit, lbs. per sq. in.	64000	58760
Ratio of Stress to Elastic Limit	.2625	.3360

Table VIII

TEST OF BOND
Between
STEEL AND CONCRETE.

TEST M				TEST N			
Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"	Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"
0	3650	193.6	18580	0	8000	333.3	32000
.005	3800	201.6	19350	.01	8700	362.5	34800
.01	3650	193.6	18580	.02	8750	364.6	35000
.015	3500	185.7	17820	.03	9100	379.2	36400
.02	3300	175.1	16800	.04	9450	393.8	37800
.025	3100	164.5	15790	.05	9900	412.5	39600
.03	2900	153.9	14760	.06	10350	431.2	41400
.035	2750	145.9	14000	.07	10900	454.2	43600
.04	2600	137.9	13240	.08	11350	472.9	45400
.045	2450	130.0	12470	.09	11700	487.5	46800
.05	2200	116.7	11200	.10	12100	504.1	48400

TEST	M	N
Age of Concrete, days	91	91
Style of Bar	Round	Twisted
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	1.57	2.00
Total Bonding Area, sq. ins.	18.85	24.00
Maximum Load, lbs.	3800	12100
Maximum Bond, lbs per sq. in.	201.6	504.1
Area of Steel, sq. ins.	.1964	.25
Stress in Steel, lbs. per sq. in.	19350	48400
Elastic Limit, lbs per sq. in.	53560	78400
Ratio Stress to Elastic Limit	.3613	.6540

Table IX

TEST OF BOND
Between
STEEL AND CONCRETE

TEST O				TEST P			
Elongation in Inches	Load in lbs	Bond lbs. per □"	Stress in Steel lbs. per □"	Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"
0	5150	214.6	20600	0	7500	265.2	16980
.005	7200	300.0	28800	.005	8450	299.8	19130
.01	8400	350.0	33600	.01	8000	283.0	18110
.015	9550	397.9	38200	.015	7400	261.7	16750
.020	10250	427.5	41000	.020	6850	242.3	15500
.025	10750	447.9	43000	.025	6450	228.1	14600
.030	11200	466.7	44800	.030	6150	217.5	13920
.035	11600	483.4	46400	.035	5850	206.9	13240
				.04	5550	196.3	12570

TEST	O	P
Age of Concrete, days	91	91
Style of Bar	Cup	Round
Size of Bar, ins.	1/2	3/4
Bonding Area per linear inch, sq. ins	2.00	2.356
Total Bonding Area, sq. ins.	24.00	28.274
Maximum Load, lbs.	11600	8450
Maximum Bond, lbs. per sq. in.	483.4	299.8
Area of Steel, sq. ins.	.25	.4418
Stress in Steel, lbs. per sq. in.	46400	19130
Elastic Limit lbs. per sq. in.	70000	66230
Ratio Stress to Elastic Limit	.6619	.2888

Table X.

TEST OF BOND
Between
STEEL AND CONCRETE.

TEST Q				TEST R			
Elongation in Inches.	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"	Elongation in Inches	Load in lbs.	Bond lbs. per □"	Stress in Steel lbs. per □"
.0	7050	195.8	12530	0	7700	213.9	13690
.005	7900	219.4	14050	.001	8500	236.1	15110
.01	8000	222.2	14220	.002	9300	258.3	16530
.015	8150	226.4	14500	.003	10100	280.6	17950
.02	8250	229.2	14670	.004	10600	294.5	18850
.025	8450	234.7	15020	.005	10950	304.2	19470
.03	8600	238.9	15290	.006	11200	311.1	19910
.035	8800	244.5	15650	.007	11300	313.9	20090
.04	8950	248.6	15910				

Test	Q	R
Age of Concrete, days	91	91
Style of Bar	Twisted	Cup
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	8950	11300
Maximum Bond, lbs. per sq. in.	248.6	313.9
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs per sq. in.	15910	20090
Elastic Limit lbs per sq. in	64000	58760
Ratio Stress to Elastic Limit	.2486	.3419

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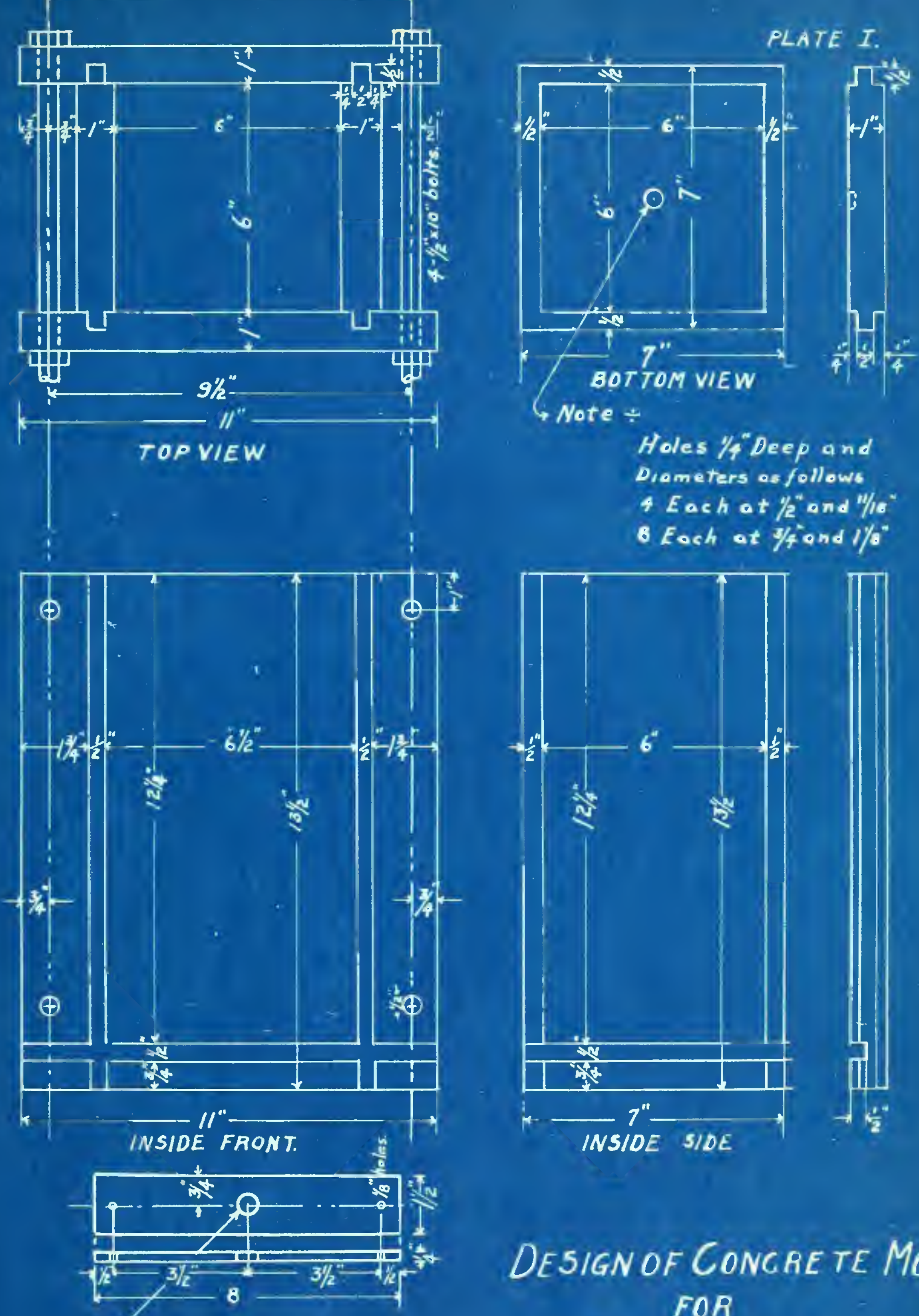
PLATE I.



Note ÷
Holes ¼" Deep and
Diameters as follows
4 Each at ½" and 11/16"
8 Each at ¾" and 1⅛"

Note ÷ – Steel –
Diameters as follows,
4 Each at ½" and 11/16"
8 Each at ¾" and 1⅛".
24 Molds Required.

DESIGN OF CONCRETE MOLDS
FOR
BONDING TEST.

ARMOUR INSTITUTE OF TECHNOLOGY.

Thesis of Alex. R. Webb.
G. H. Wilsey

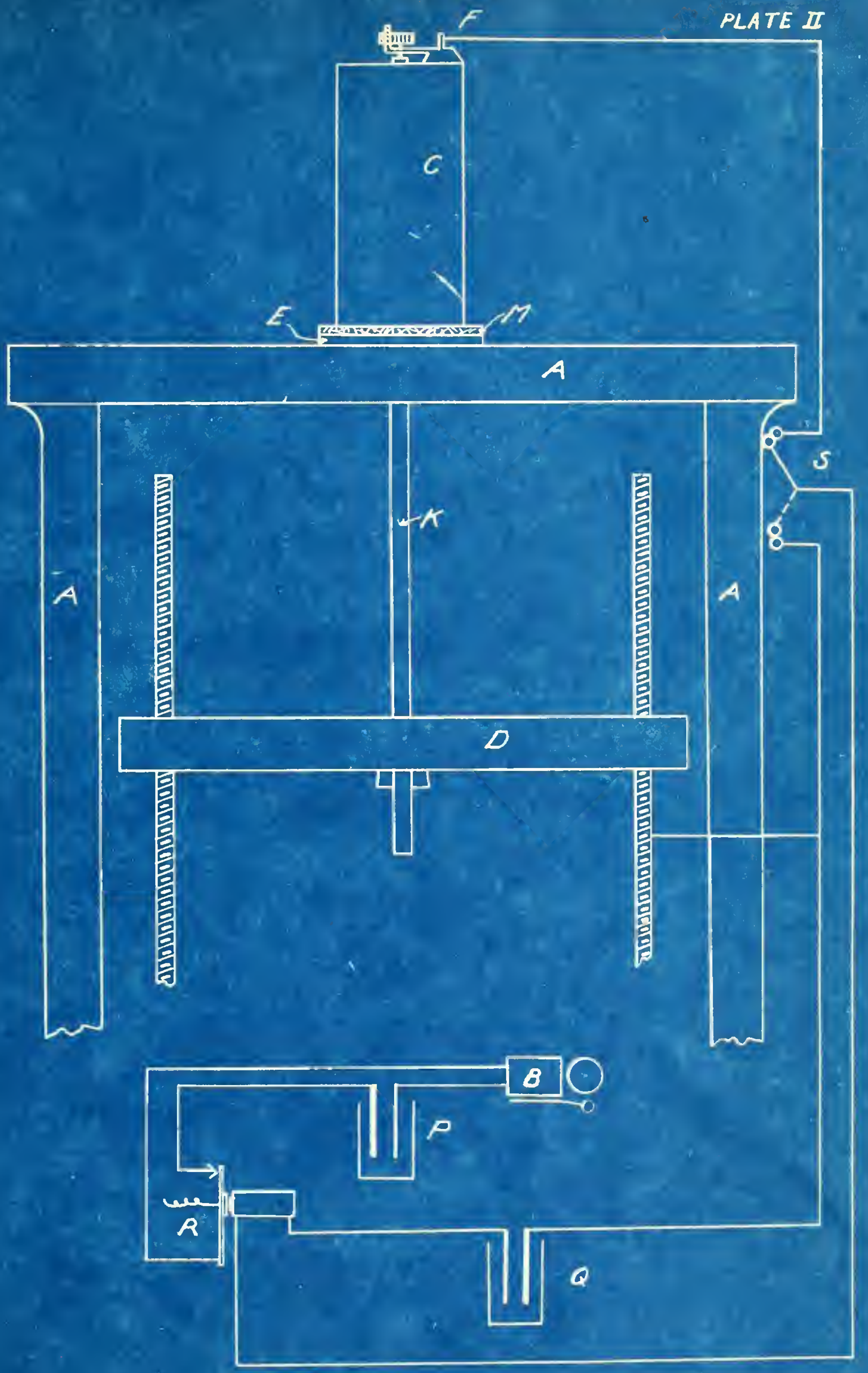

F
C
E
M
A
S
K
A
A
D
B
P
R
Q

PLATE III

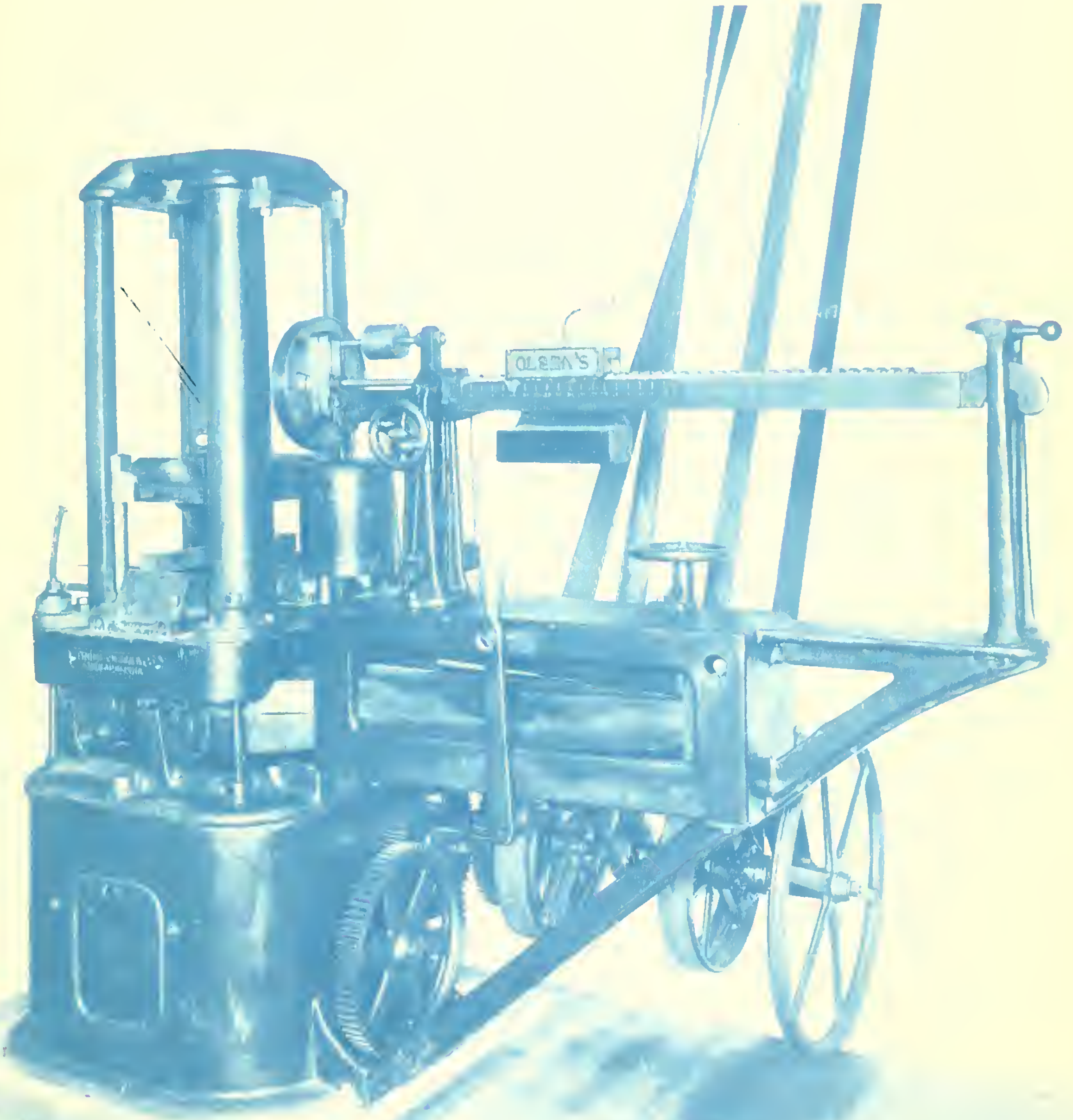
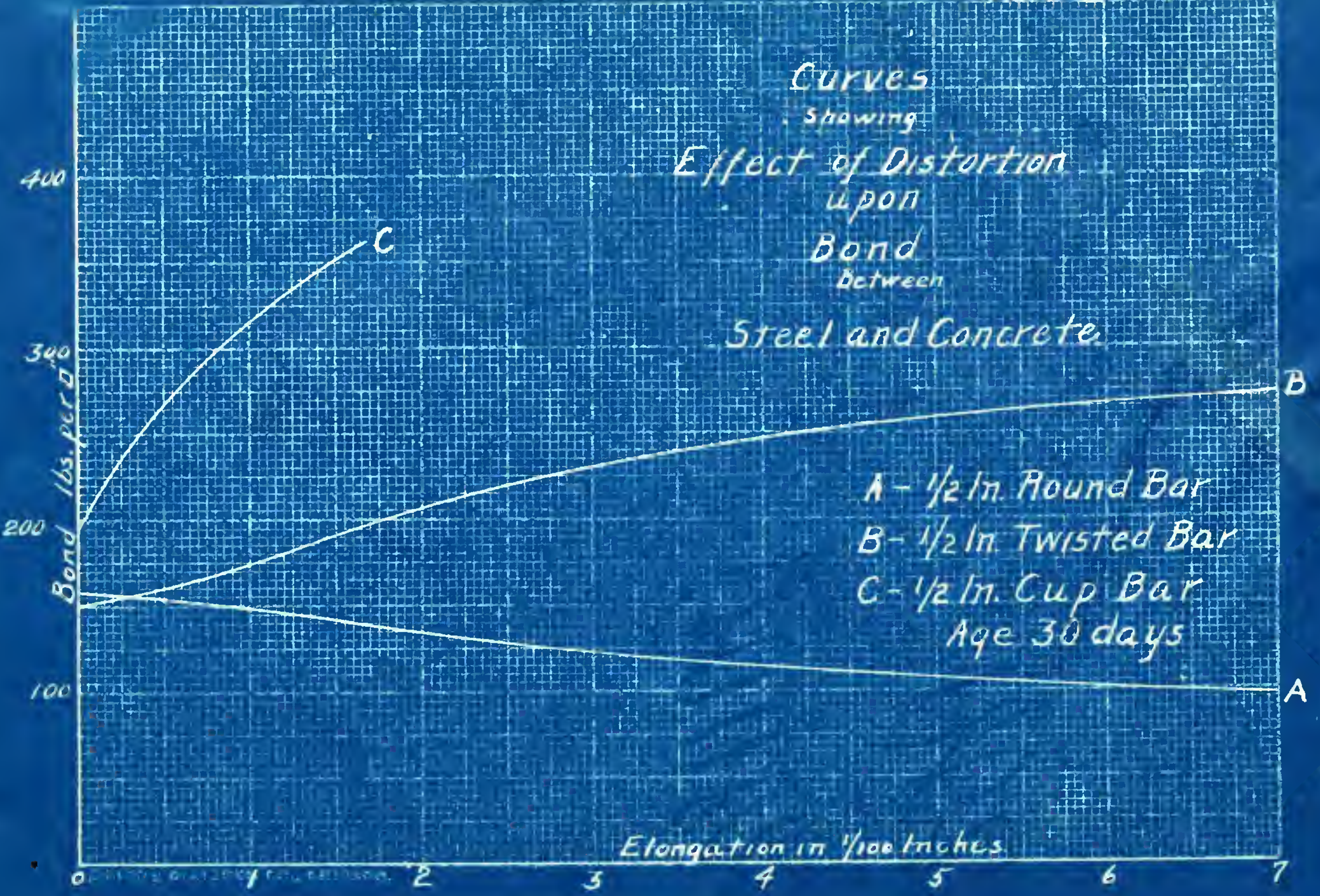


PLATE IV

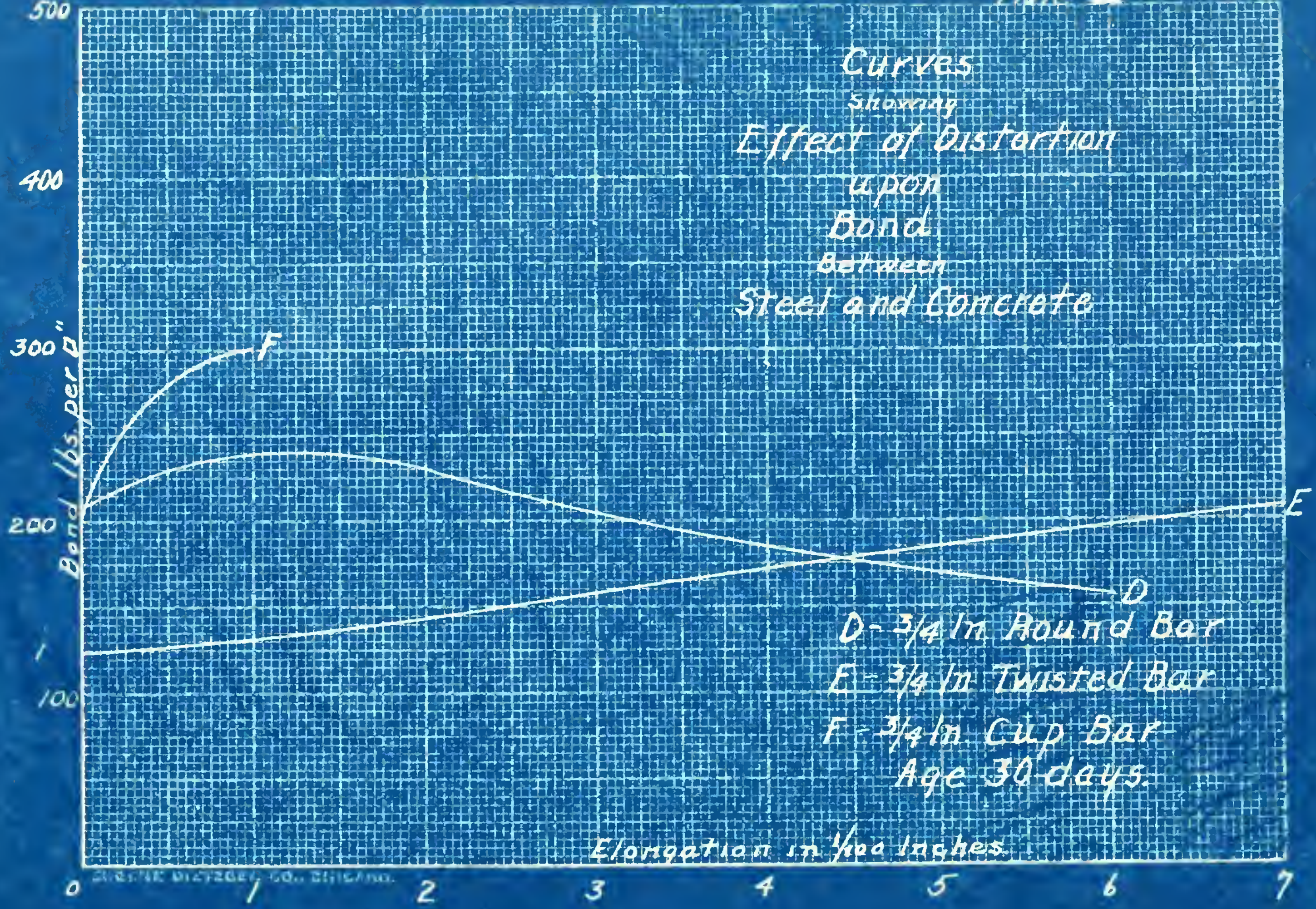
Plate V



Curves
showing
Effect of Distortion
upon
Bond
between
Steel and Concrete.

A - 1/2 In. Round Bar
B - 1/2 In. Twisted Bar
C - 1/2 In. Cup Bar
Age 30 days

Plate VII



Curves
showing
Effect of Distortion
upon
Bond
Between
Steel and Concrete

D - 3/4 In. Round Bar
E - 3/4 In. Twisted Bar
F - 3/4 In. Cup Bar
Age 30 days.

Plate VIII

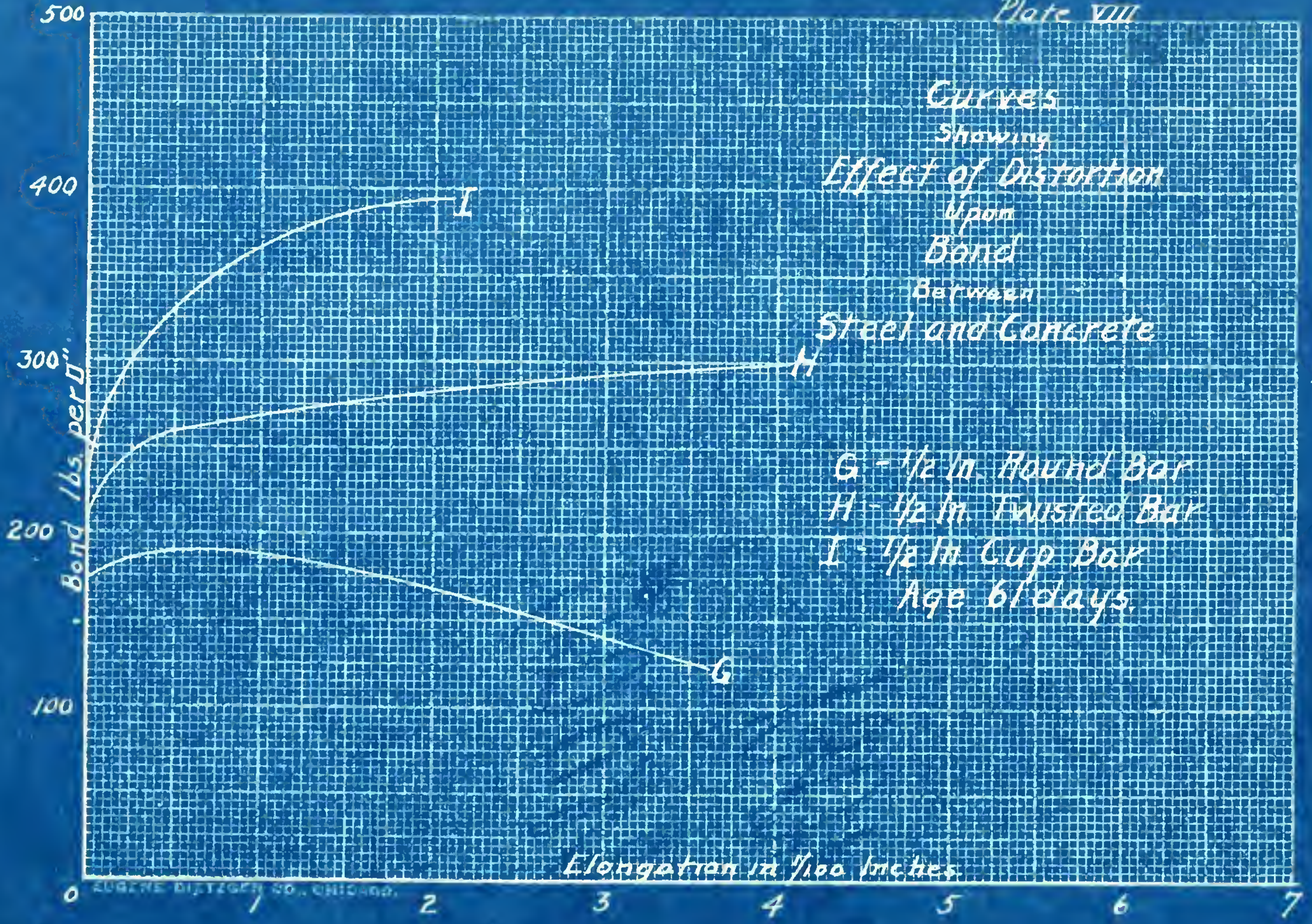

Curves
Showing
Effect of Distortion
Upon
Bond
Between
Steel and Concrete
G - 1/2 In. Round Bar
H - 1/2 In. Twisted Bar
I - 1/2 In. Cup Bar
Age 61 days.
Bond lbs. per □"
0
100
200
300
400
500
Elongation in 1/100 Inches
1
2
3
4
5
6
7
G
H
I
EUGENE DIETZGEN CO., CHICAGO.

Plate IX

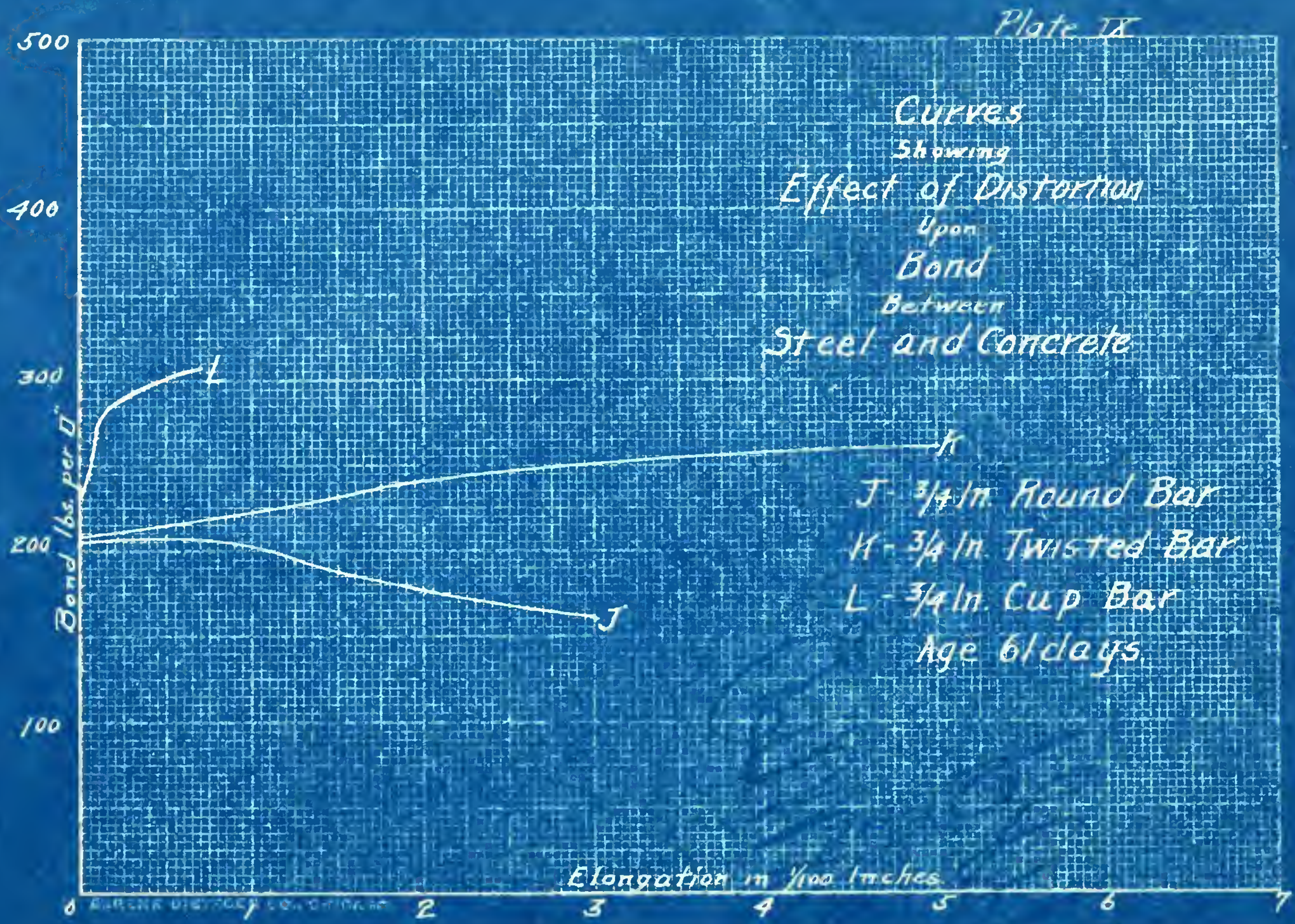

Curves
Showing
Effect of Distortion
Upon
Bond
Between
Steel and Concrete
J - 3/4 In. Round Bar
K - 3/4 In. Twisted Bar
L - 3/4 In. Cup Bar
Age 61 days
Bond lbs. per □"
500
400
300
200
100
0
Elongation in 1/100 Inches
1
2
3
4
5
6
7
L
K
J

Plate X

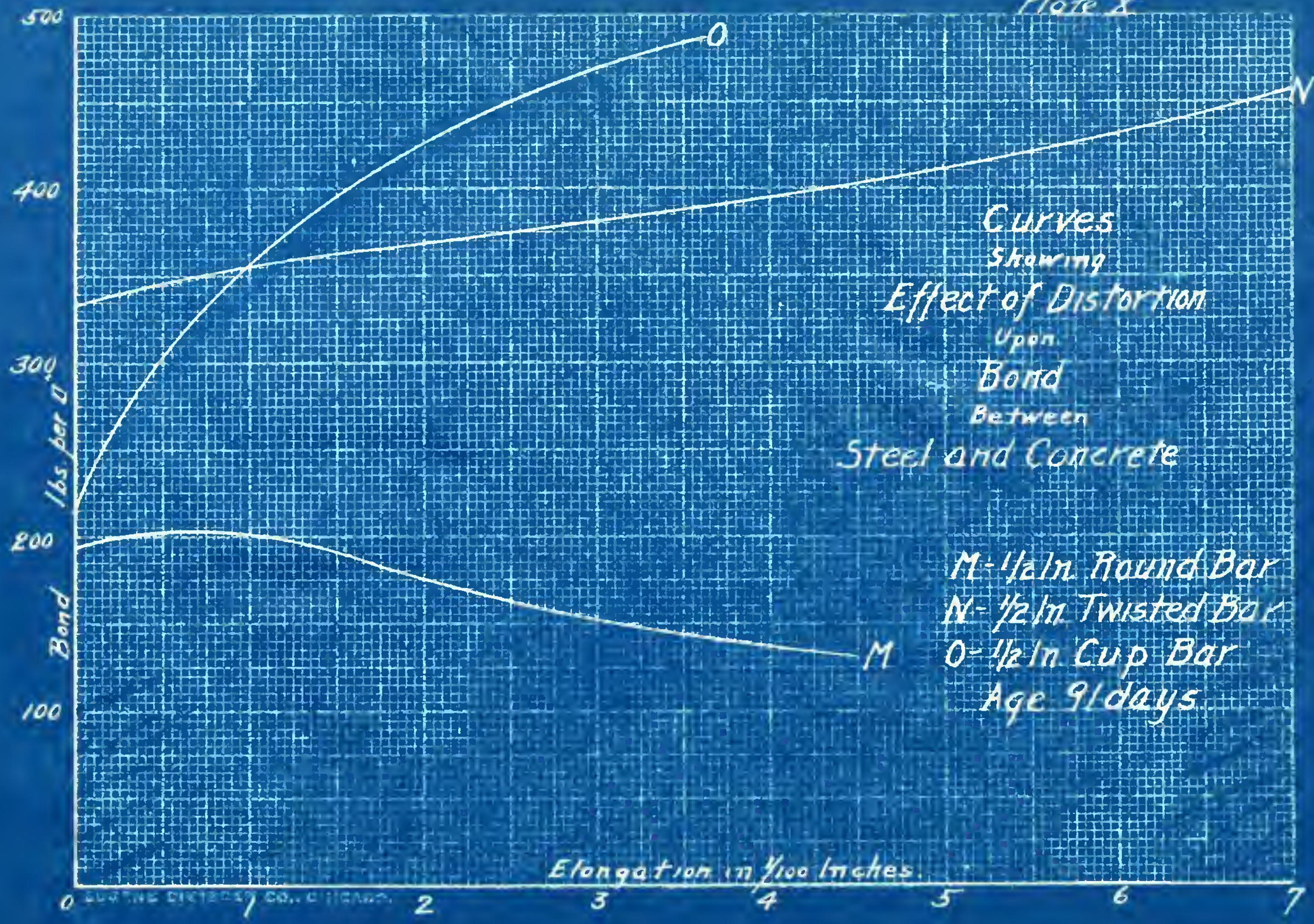

Curves
Showing
Effect of Distortion
Upon
Bond
Between
Steel and Concrete
M-1/2 In Round Bar
N-1/2 In Twisted Bar
O-1/2 In Cup Bar
Age 91 days
Bond lbs per □"
500
400
300
200
100
0
1
2
3
4
5
6
7
Elongation in 1/100 Inches
O
N
M

Plate XI

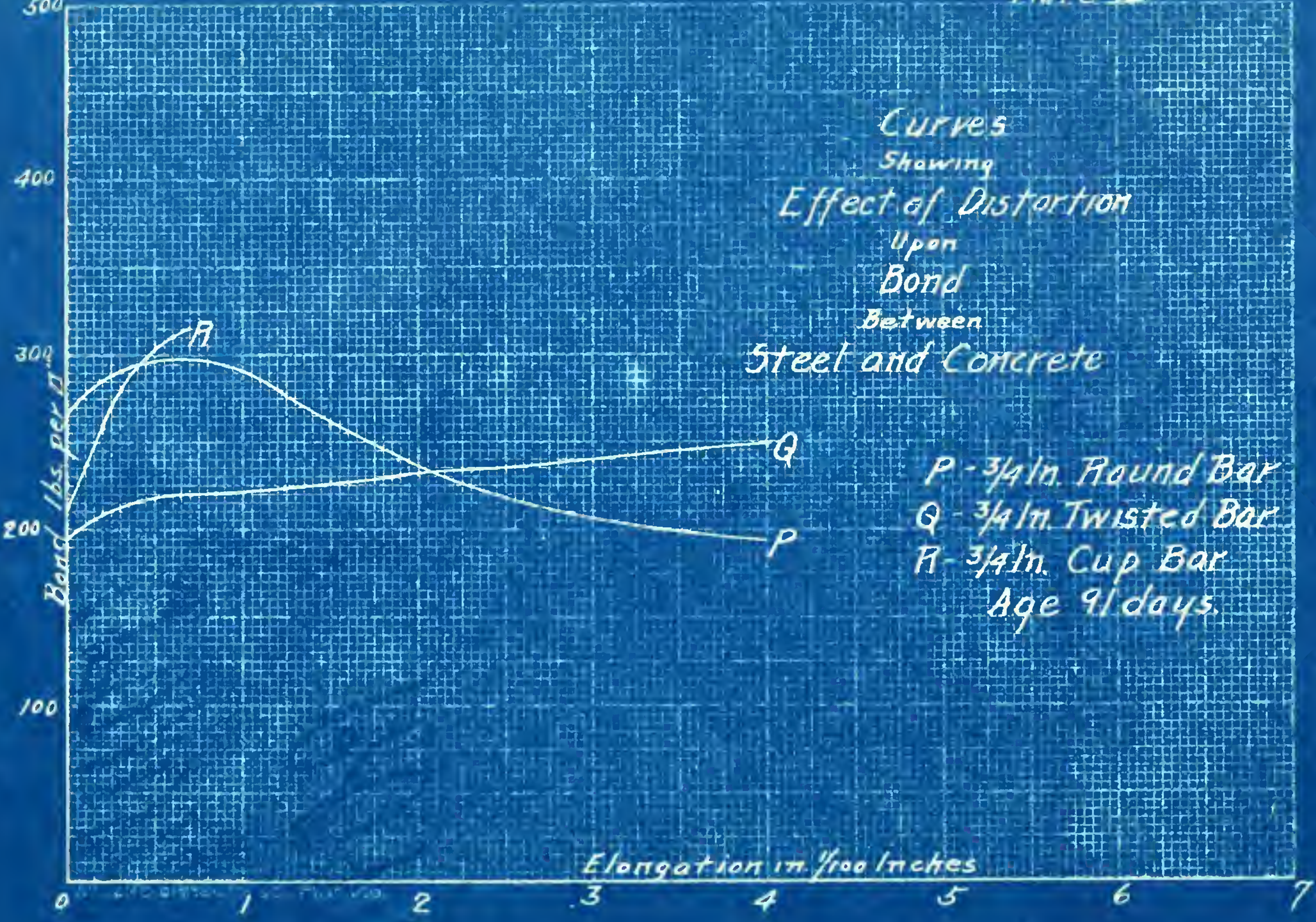

Curves
Showing
Effect of Distortion
Upon
Bond
Between
Steel and Concrete
P - 3/4 In. Round Bar
Q - 3/4 In. Twisted Bar
R - 3/4 In. Cup Bar
Age 91 days.
Bond lbs. per □"
500
400
300
200
100
0
1
2
3
4
5
6
7
Elongation in 1/100 Inches
P
Q
R

Plate XII

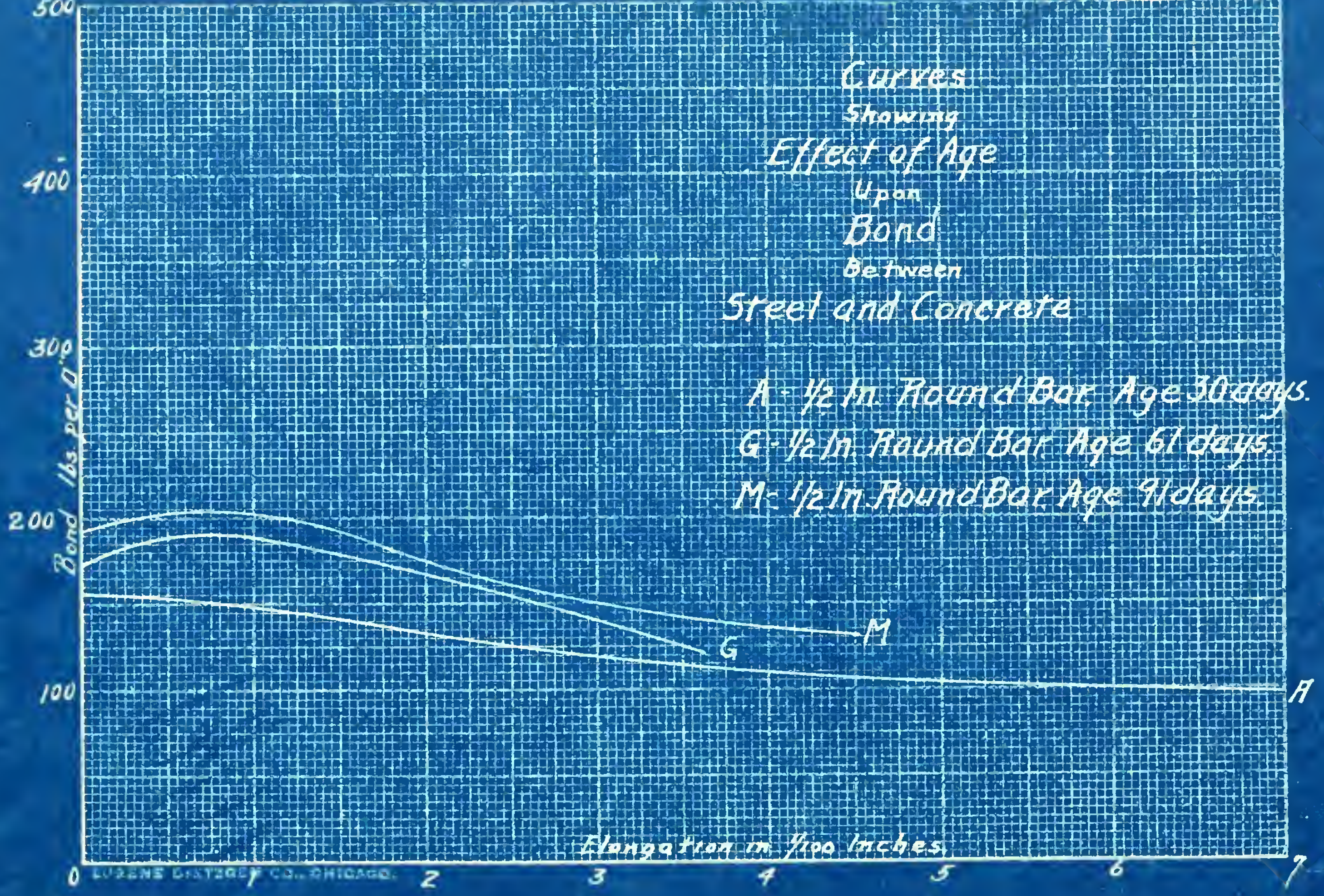
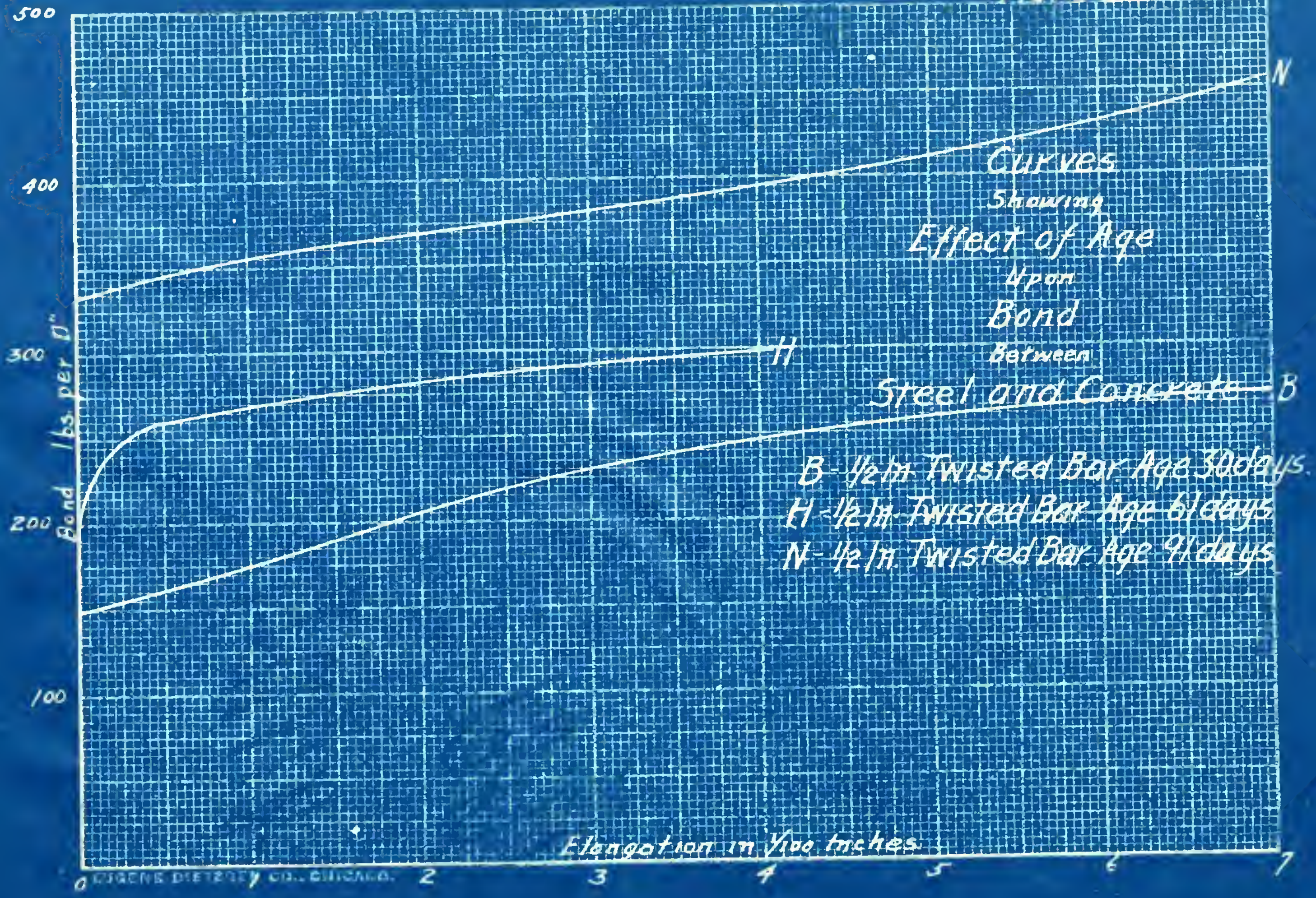

Curves
Showing
Effect of Age
Upon
Bond
Between
Steel and Concrete
A - 1/2 In. Round Bar Age 30 days.
G - 1/2 In. Round Bar Age 61 days.
M - 1/2 In. Round Bar Age 91 days.
Bond lbs. per □"
500
400
300
200
100
0
1
2
3
4
5
6
7
Elongation in 1/100 Inches
A
G
M
EUGENE DIETZGEN CO., CHICAGO.

Plate XIII


Curves
Showing
Effect of Age
Upon
Bond
Between
Steel and Concrete
B- 1/2 in. Twisted Bar Age 30 days.
H- 1/2 in. Twisted Bar Age 61 days
N- 1/2 in. Twisted Bar Age 91 days
N
H
B
Bond lbs. per □"
500
400
300
200
100
0
2
3
4
5
6
7
Elongation in 1/100 inches.
EUGENE DIETZGEN CO., CHICAGO.

[illegible]
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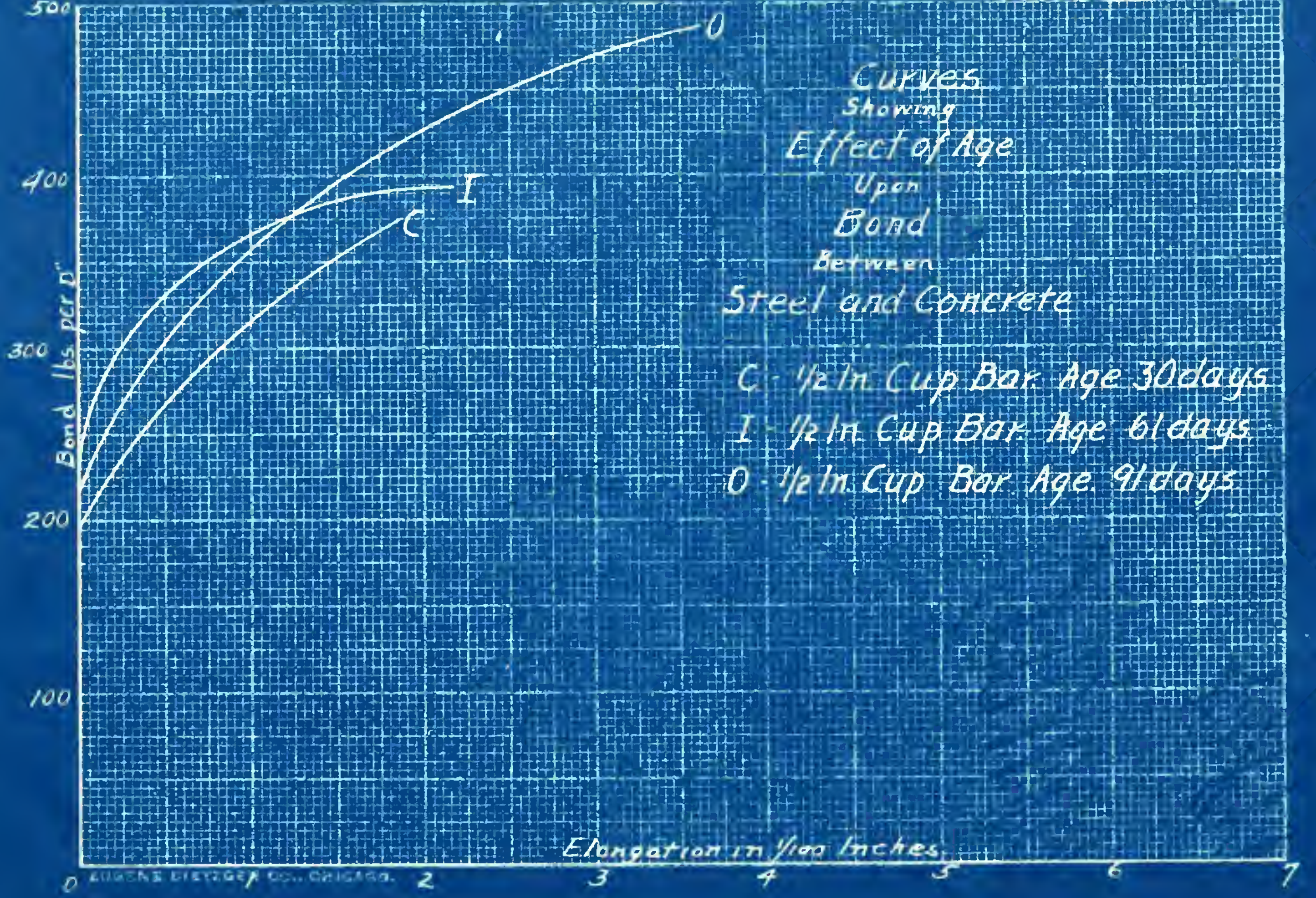
Plate XIV


Curves
Showing
Effect of Age
Upon
Bond
Between
Steel and Concrete
C - ½ In. Cup Bar. Age 30 days
I - ½ In. Cup Bar. Age 61 days
O - ½ In. Cup Bar. Age 91 days
Bond lbs. per □"
500
400
300
200
100
0
2
3
4
5
6
7
Elongation in 1/100 Inches.
O
I
C
EUGENE DIETZGEN CO., CHICAGO.

[illegible]
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Plate XV

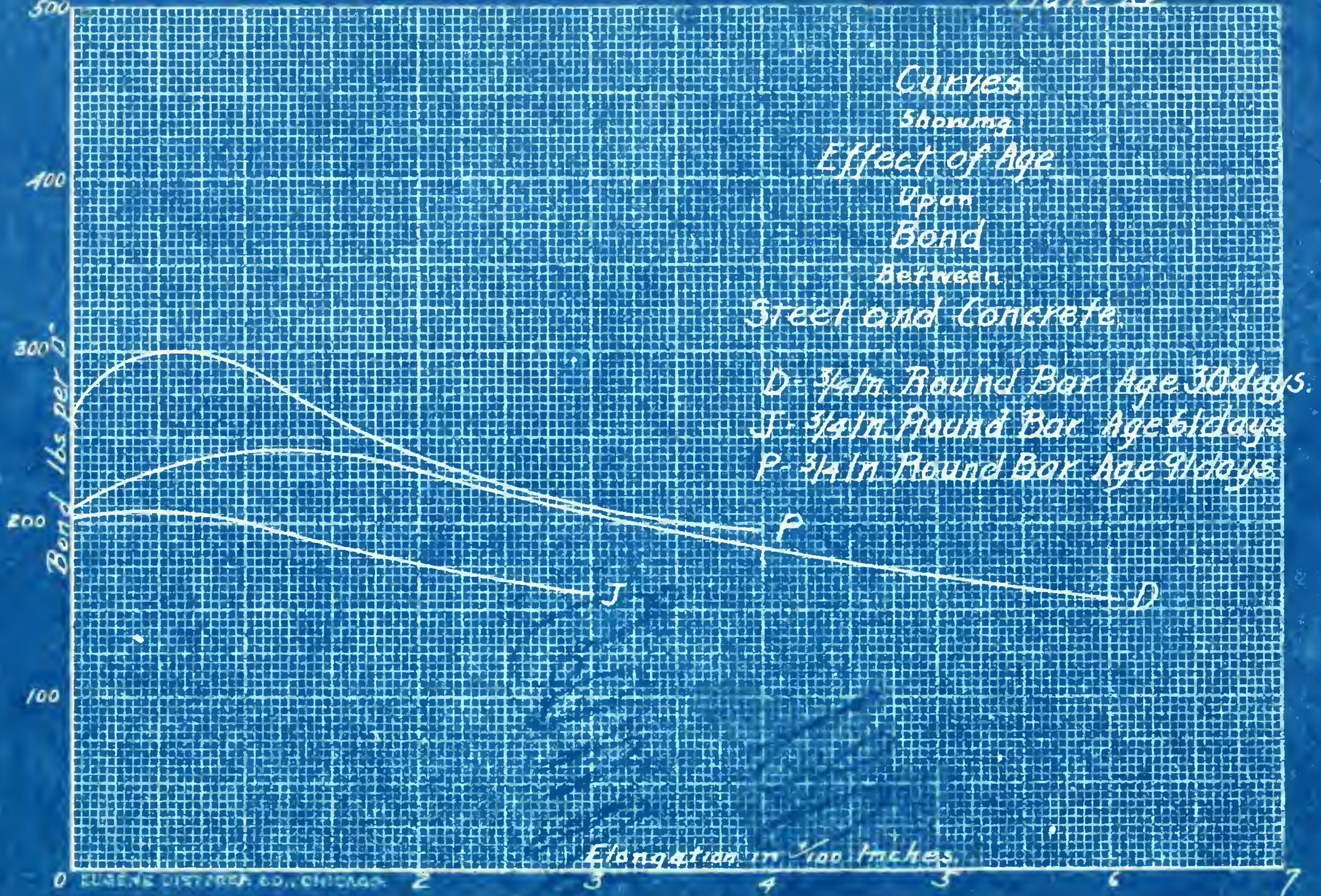
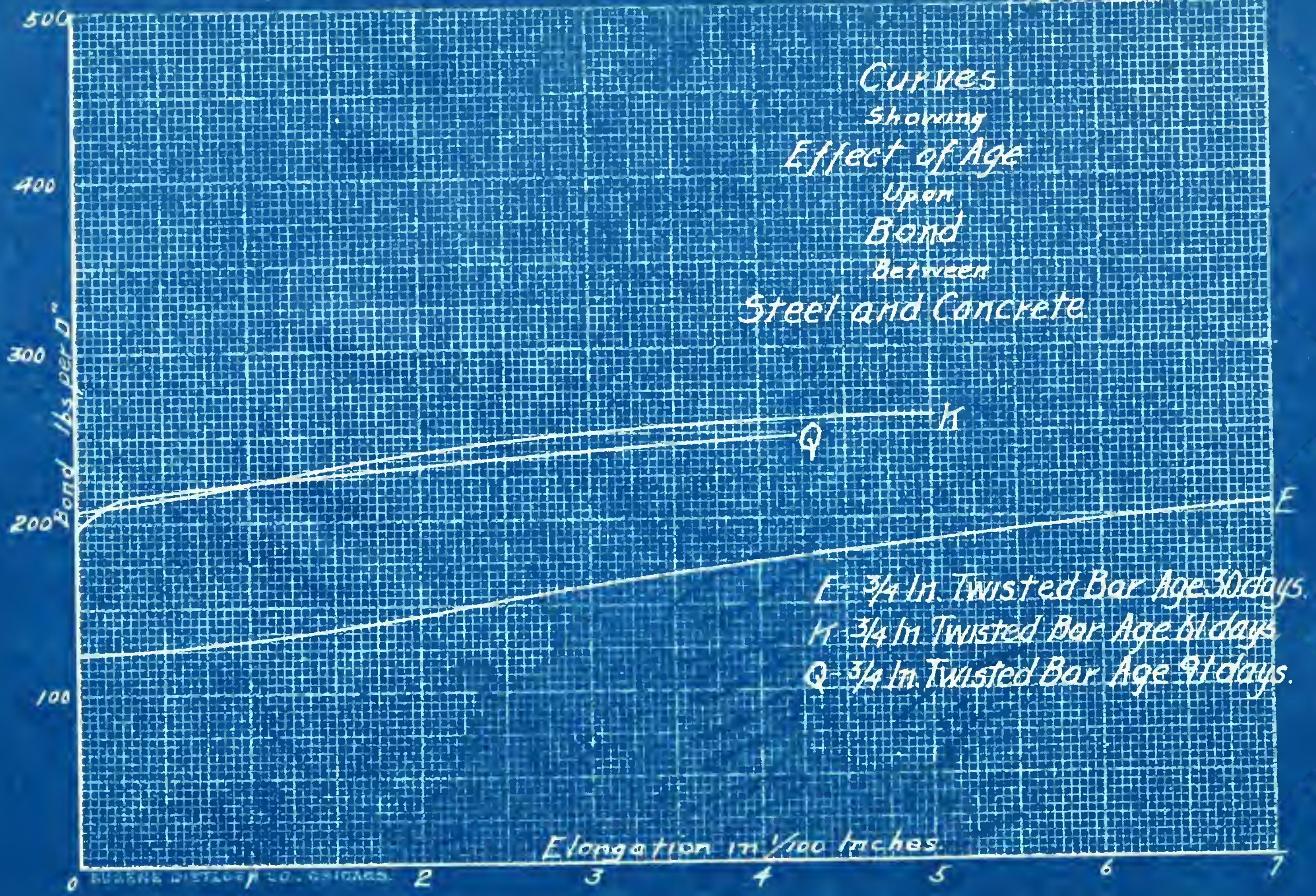

Curves
Showing
Effect of Age
Upon
Bond
Between
Steel and Concrete.
D-¾In. Round Bar Age 30days.
J-¾In. Round Bar Age 61days
P-¾In. Round Bar Age 91days
Bond lbs per □"
500
400
300
200
100
0
2
3
4
5
6
7
Elongation in 1/100 Inches
J
P
D
EUGENE DIETZGEN CO., CHICAGO.

Plate XVI


Curves
Showing
Effect of Age
Upon
Bond
Between
Steel and Concrete
Bond lbs. per □"
500
400
300
200
100
0
2
3
4
5
6
7
Elongation in 1/100 Inches
K
Q
E
E - 3/4 In. Twisted Bar Age 30 days.
K - 3/4 In. Twisted Bar Age 61 days.
Q - 3/4 In. Twisted Bar Age 91 days.
EUGENE DIETZGEN CO. CHICAGO.

[illegible]
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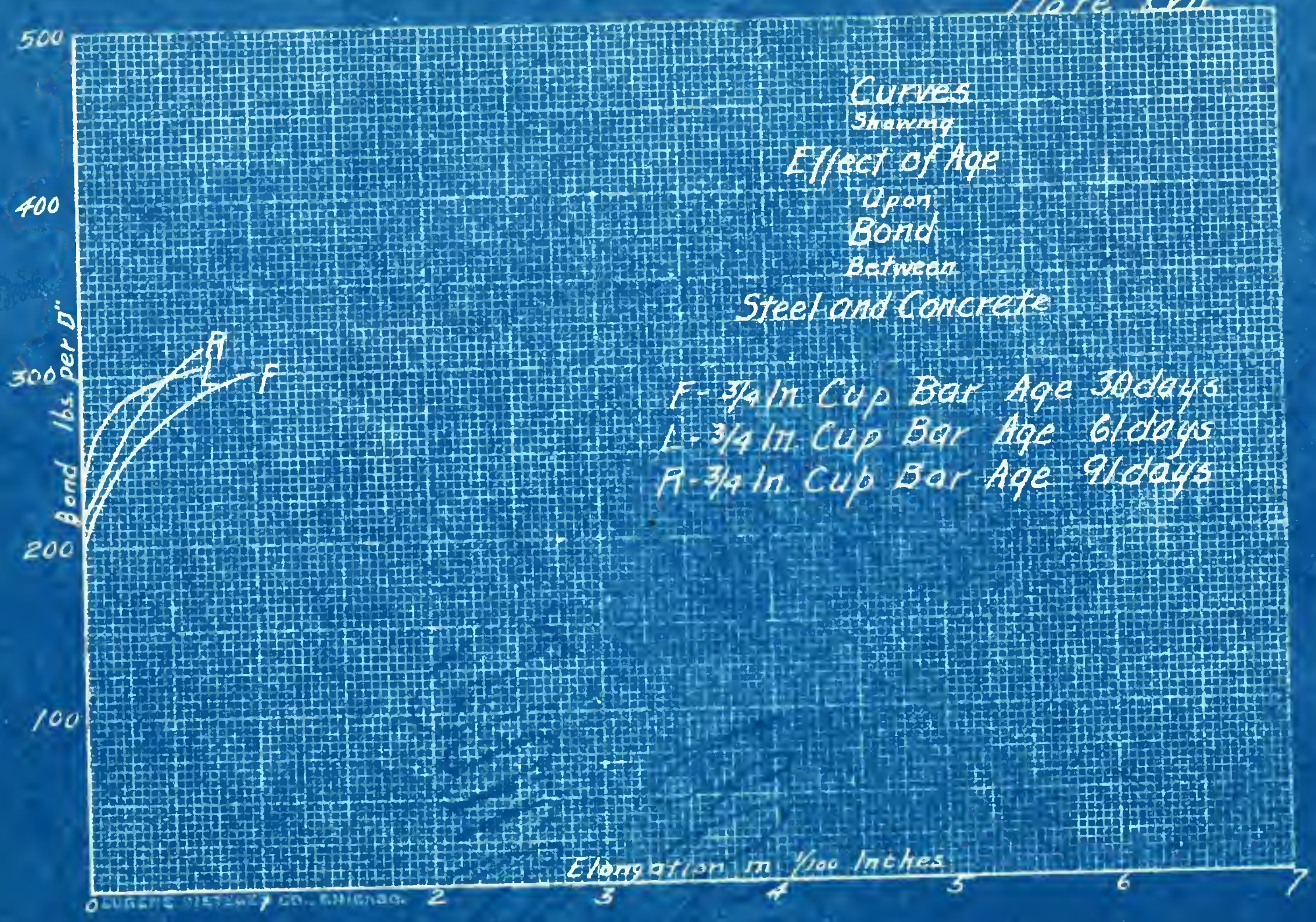
Plate XVII


Curves
Showing
Effect of Age
Upon
Bond
Between
Steel and Concrete
F - 3/4 In. Cup Bar Age 30 days
L - 3/4 In. Cup Bar Age 61 days
A - 3/4 In. Cup Bar Age 91 days
Bond lbs. per □"
500
400
300
200
100
0
2
3
4
5
6
7
Elongation in 1/100 Inches
F
L
A

[illegible]
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APPENDIX

to report on

Bonding Strength of Concrete and Steel

consisting of

Log Sheets and Load-Slip Curves

of Individual Tests

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 1			Test No. 2		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.3722		200	.3370	
3890	.3775	.0053	1750	.3398	.0018
2730	.4301	.0579	1370	.3878	.0508
2408	.4476	.0754	1000	.4193	.0823
1960	.4807	.1085	800	.4508	.1138
1640	.5206	.1484	620	.5059	.1689
1400	.5374	.1652			

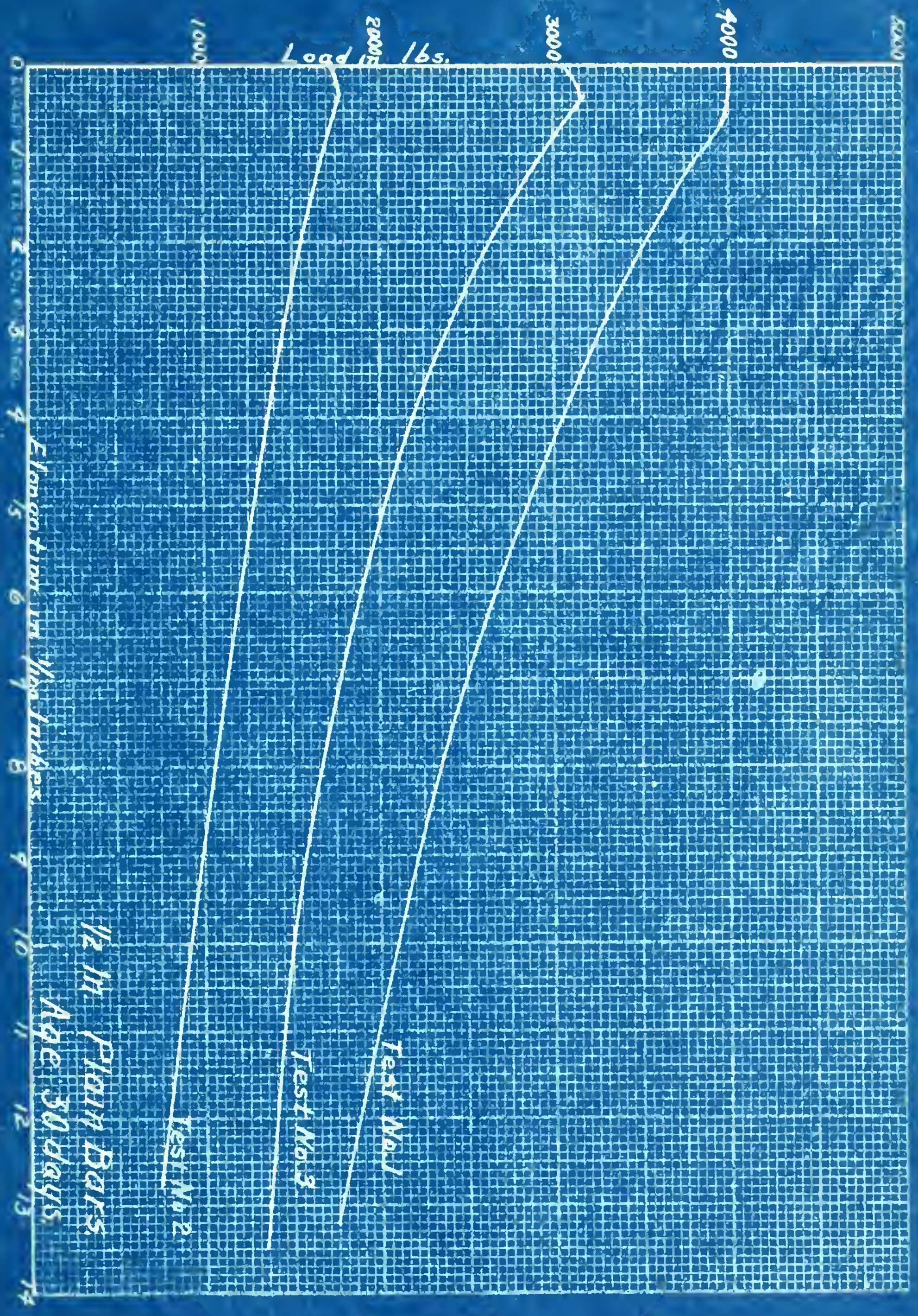
Test No.	1	2
Age of Concrete, days	30	30
Size of Bar, ins.	½	½
Bonding Area per linear inch, sq. ins.	1.57	1.57
Total Bonding Area, sq. ins.	18.85	18.85
Maximum Load, lbs.	3890	1750
Maximum Bond, lbs. per sq. in.	206.4	92.8
Area of Steel, sq. ins.	.1964	.1964
Stress in Steel, lbs. per sq. in.	19810	8910
Elastic Limit, lbs. per sq. in.	53560	53560
Ratio of Stress to Elastic Limit	.3699	.1662

Log of Test of Plain Bars

Thesis of H. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 3			Test No.		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5117				
2750	.5114	.0003			
3110	.5108	.0009			
3180	.5083	.0034			
2530	.4864	.0253			
2080	.4664	.0453			
1700	.4411	.0706			
1480	.4083	.1034			
1320	3766	.1351			

Test No.	3	
Age of Concrete, days	30	
Size of Bar, ins.	½	
Bonding Area per linear inch, sq. ins.	1.57	
Total Bonding Area, sq. ins.	18.85	
Maximum Load, lbs.	3180	
Maximum Bond, lbs. per sq. in.	168.7	
Area of Steel, sq. ins.	.1964	
Stress in Steel, lbs. per sq. in.	16190	
Elastic Limit, lbs. per sq. in.	53560	
Ratio of Stress to Elastic Limit	.3026	


Load in lbs.
1000
2000
3000
4000
5000
Elongation in 1/100 inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Test No. 1
Test No. 3
Test No. 2
1/2 in Plain Bars
Age 30 days

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 4			Test No. 4		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5806		8420	.4637	.1169
2860	.5676	.0130	6390	.4436	.1370
3660	.5648	.0158	2490	.3861	.1945
3750	.5622	.0184			
3950	.5592	.0214			
4100	.5539	.0267			
4300	.5382	.0424			
4960	.5367	.0439			
5200	.5341	.0465			
5350	.5307	.0499			
5760	.5236	.0570			
6170	.5188	.0618			
6650	.5127	.0679			
7280	.4991	.0815			
7970	.4925	.0981			

Test No.	4	
Age of Concrete, days	30	
Size of Bar, ins.	1/2	
Bonding Area per linear inch, sq. ins.	2.00	
Total Bonding Area, sq. ins.	24.00	
Maximum Load, lbs.	8420	
Maximum Bond, lbs. per sq. in.	350.9	
Area of Steel, sq. ins.	.25	
Stress in Steel, lbs. per sq. in.	33680	
Elastic Limit, lbs. per sq. in.	78400	
Ratio of Stress to Elastic Limit	.4296	

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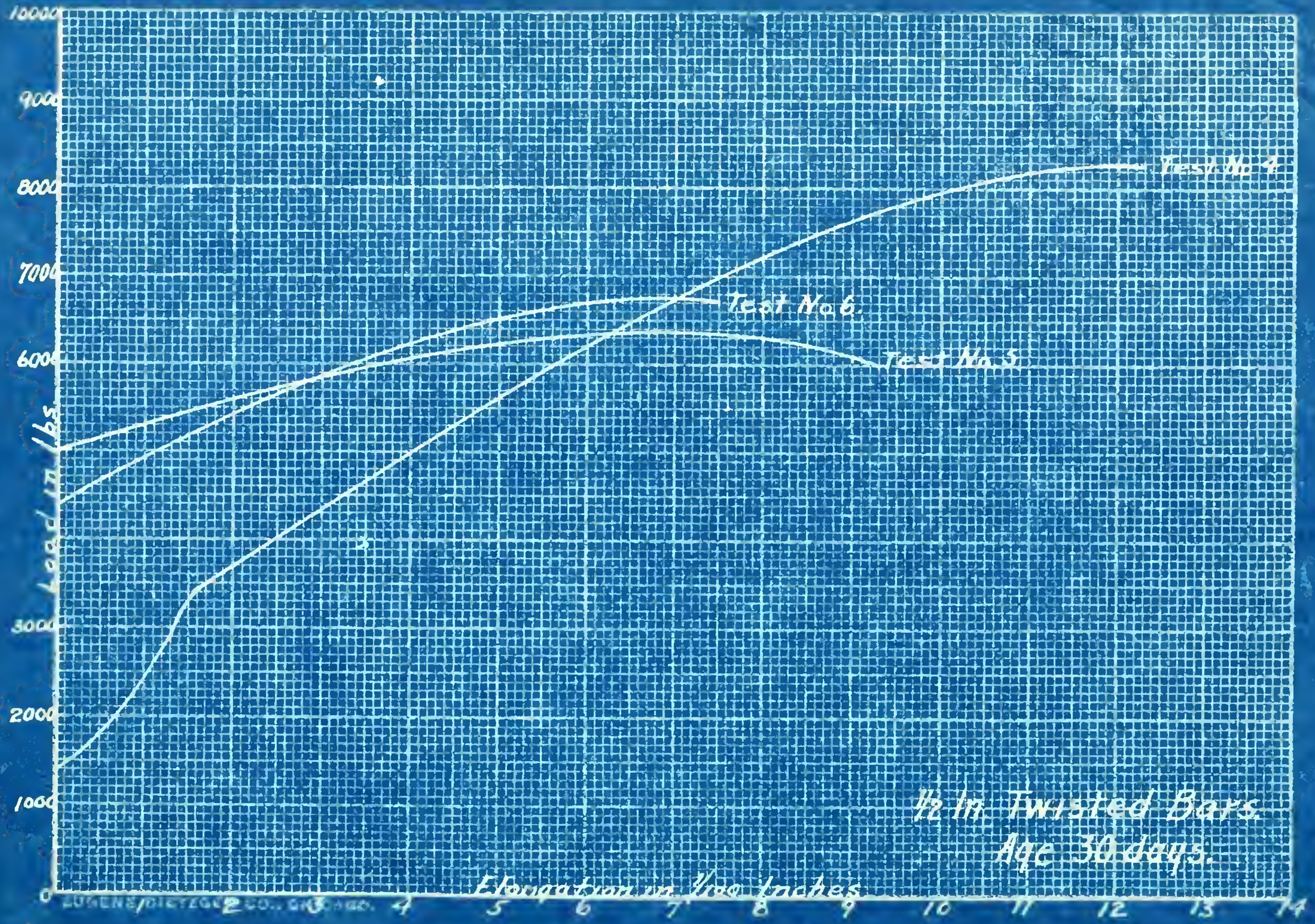
Log of Test of Twisted Bars

Thesis of H. R. Webb and S. H. Wiley
Armour Institute of Technology

Test No. 5			Test No. 6		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	6034		200	.5883	
3800	.6026	.0008	4340	.5881	.0002
5040	.6012	.0022	4590	.5864	.0019
5660	.5874	.0160	4960	.5758	.0125
5880	.5691	.0343	5580	.5628	.0255
6250	.5472	.0562	6270	.5515	.0368
6330	.5248	.0786	6710	.5276	.0607
4700	.4923	.1111	6500	.5120	.0763
4020	.4896	.1138	6000	.4886	.0997
2750	.4546	.1488	4700	.4533	.1350
2550	.4536	.1498			

Test No.	5	6
Age of Concrete, days	30	30
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	2.00	2.00
Total Bonding Area, sq. ins.	24.00	24.00
Maximum Load, lbs.	6330	6710
Maximum Bond, lbs. per sq. in.	263.8	279.6
Area of Steel, sq. ins.	.25	.25
Stress in Steel, lbs. per sq. in.	25320	26840
Elastic Limit, lbs. per sq. in.	78400	78400
Ratio of Stress to Elastic Limit	.3230	.3423


Load in lbs.
0
1000
2000
3000
6000
7000
8000
9000
10000
Elongation in 1/100 Inches
2
3
4
5
6
7
8
9
10
11
12
13
14
EUGENE DIETZGEN CO., CHICAGO.
Test No. 4
Test No. 6.
Test No. 5.
1/2 In. Twisted Bars.
Age 30 days.

Log of Test of Cup Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 7			Test No. 8		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5862		200	.6808	
3980	.5852	.0010	5190	.6803	.0005
4670	.5845	.0017	6000	.6798	.0010
5370	.5831	.0031	6710	.6782	.0026
6000	.5805	.0057	7550	.6771	.0037
6620	.5749	.0113	8140	.6746	.0062
7260	.5631	.0231	8780	.6667	.0141
3870	.5200	.0662	4910	.6223	.0585
2770	4792	.1070	4000	.6208	.0600
			3050	.5849	.0959

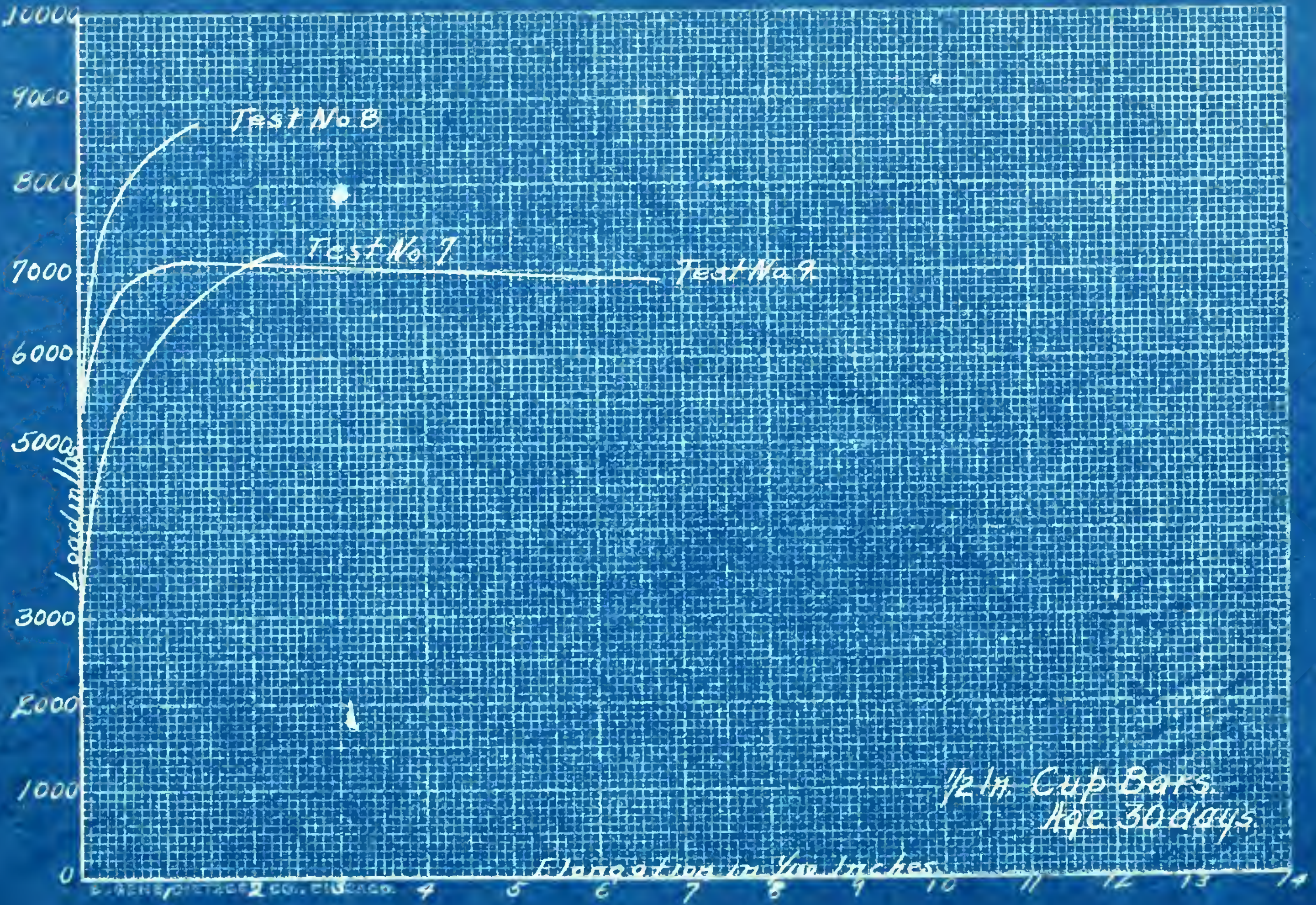
Test No.	7	8
Age of Concrete, days	30	30
Size of Bar, ins.	½	½
Bonding Area per linear inch, sq. ins.	2.00	2.00
Total Bonding Area, sq. ins.	24.00	24.00
Maximum Load, lbs.	7260	8780
Maximum Bond, lbs. per sq. in.	302.5	365.8
Area of Steel, sq. ins.	.25	.25
Stress in Steel, lbs. per sq. in.	29040	35120
Elastic Limit, lbs. per sq. in.	70000	70000
Ratio of Stress to Elastic Limit	.4149	.5017

Log of Test of Cup Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 9			Test No.		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5906				
6310	.5884	.0012			
7040	.5850	.0056			
6880	.5229	.0677			
2750	.4160	.0736			

Test No.	9	
Age of Concrete, days	30	
Size of Bar, ins.	1/2	
Bonding Area per linear inch, sq. ins.	2.00	
Total Bonding Area, sq. ins.	24.00	
Maximum Load, lbs.	7040	
Maximum Bond, lbs. per sq. in.	293.4	
Area of Steel, sq. ins.	.25	
Stress in Steel, lbs. per sq. in.	28160	
Elastic Limit, lbs. per sq. in.	70 000	
Ratio of Stress to Elastic Limit	.4023	



1/2 in. Cup Bars.
Age 30 days.

Log of Test of Plain Bars

Thesis of K. R. Webb and S. H. Wiley
Armour Institute of Technology

Test No. 10			Test No. 11		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.3875		200	.6019	
3090	.3859	.0016	5670	.6010	.0009
3710	.3673	.0202	6200	.5991	.0028
3010	.3363	.0512	5800	.5984	.0035
2670	.3132	.0743	5250	.5826	0193
2240	.2810	.1065	4150	.5633	0385
1960	.2363	.1512	3680	.5432	0587

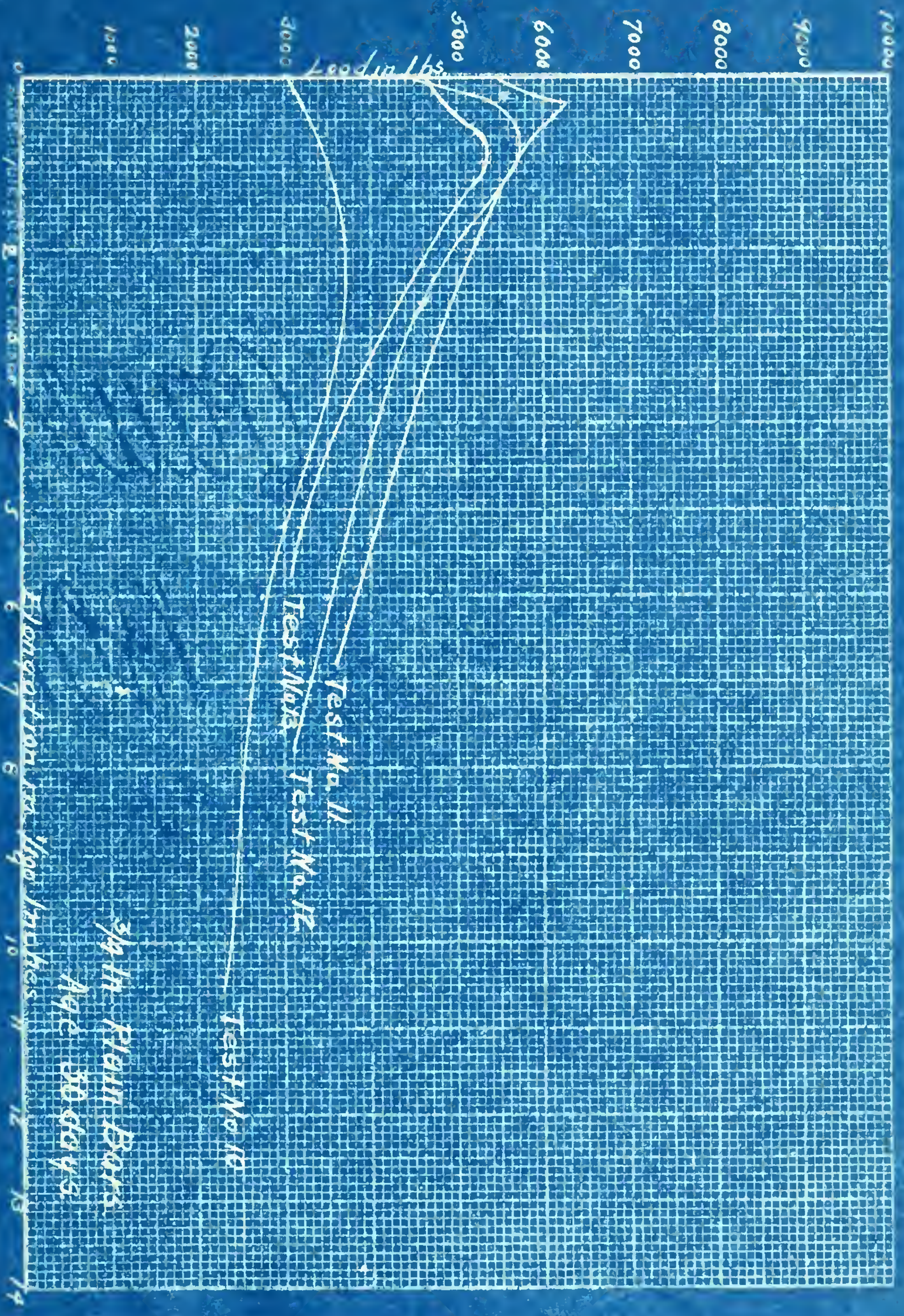
Test No.	10	11
Age of Concrete, days	30	30
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	2.356	2.356
Total Bonding Area, sq. ins.	28.274	28.274
Maximum Load, lbs.	3710	6200
Maximum Bond, lbs. per sq. in.	131.2	219.4
Area of Steel, sq. ins.	.4418	.4418
Stress in Steel, lbs. per sq. in.	8397	14030
Elastic Limit, lbs. per sq. in.	66230	66230
Ratio of Stress to Elastic Limit	.1268	.2118

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 12			Test No. 13		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5010		200	4967	
4530	.5005	.0005	4747	4958	0009
5250	.4996	.0014	5200	4898	0069
5800	.4929	.0081	5510	4896	0071
4570	.4747	.0263	4140	4643	0324
3520	.4406	.0604	3140	4392	0575
3110	.4229	.0781			

Test No.	12	13
Age of Concrete, days	30	30
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	2.356	2.356
Total Bonding Area, sq. ins.	28.274	28.274
Maximum Load, lbs.	5800	5510
Maximum Bond, lbs. per sq. in.	205.2	194.9
Area of Steel, sq. ins.	.4418	.4418
Stress in Steel, lbs. per sq. in.	13130	12470
Elastic Limit, lbs. per sq. in.	66230	66230
Ratio of Stress to Elastic Limit	.1982	.1883


Load in lbs.
1000
2000
3000
5000
6000
7000
8000
9000
10000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Elongation in 1/100 Inches
Test No. 11
Test No. 12
Test No. 12
Test No. 12
3/4 in Plain Bars
Age 30 days

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 14			Test No. 15		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5501		200	.5712	
5680	.5479	.0022	6090	.5416	.0296
5900	.5384	.0117	6450	.5375	.0337
6230	.5202	.0299	6670	.5357	.0355
6730	.5018	.0483	7170	.5205	.0507
7100	.4746	.0755	7880	.5005	.0707
6700	.4541	.0960	8180	.4849	.0863
5000	.4131	.1370	7550	.4684	.1028
			5210	.4319	.1393

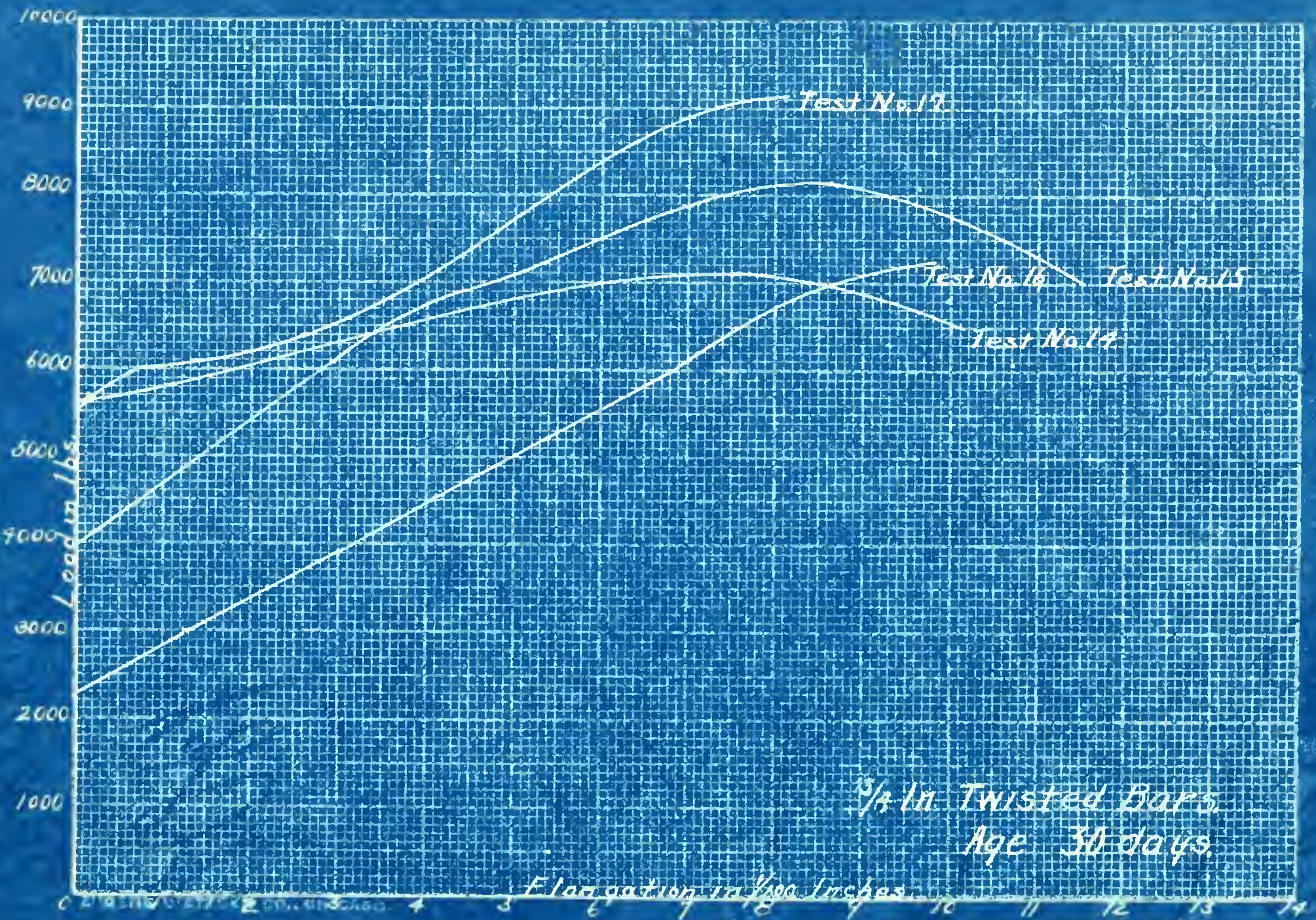
Test No.	14	15
Age of Concrete, days	30	30
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	7100	8180
Maximum Bond, lbs. per sq. in.	197.2	227.2
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	12620	14540
Elastic Limit, lbs. per sq. in.	64000	64000
Ratio of Stress to Elastic Limit	.1472	.2272

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 16			Test No. 17		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5640		200	.5745	
2380	.5628	.0012	5760	.5728	.0017
2600	.5604	.0036	6000	.5675	.0070
3000	.5516	.0124	6580	.5431	.0314
3540	.5420	.0220	7350	.5317	.0428
4000	.5316	.0324	8150	.5180	.0565
5000	.5136	.0504	9120	.4935	.0810
6000	.4957	.0683			
7000	.4793	.0847			
7240	.4655	.0985			

Test No.	16	17
Age of Concrete, days	30	30
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	7240	9120
Maximum Bond, lbs. per sq. in.	201.1	253.3
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	12870	16210
Elastic Limit, lbs. per sq. in.	64000	64000
Ratio of Stress to Elastic Limit	.2011	.2533



5/8 In. Twisted Bars.
Age 30 days.

Log of Test of Cup Bars

Thesis of A. R. Webb and S. H. Wilsey

Armour Institute of Technology

Test No. 18			Test No. 19		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5130		200	.5635	
10200	.5090	.0039	10380	.5619	.0016
10430	.5040	.0090	11000	.5608	.0027
5490	.4639	.0491	11540	.5590	.0045
			11610	.5330	.0305

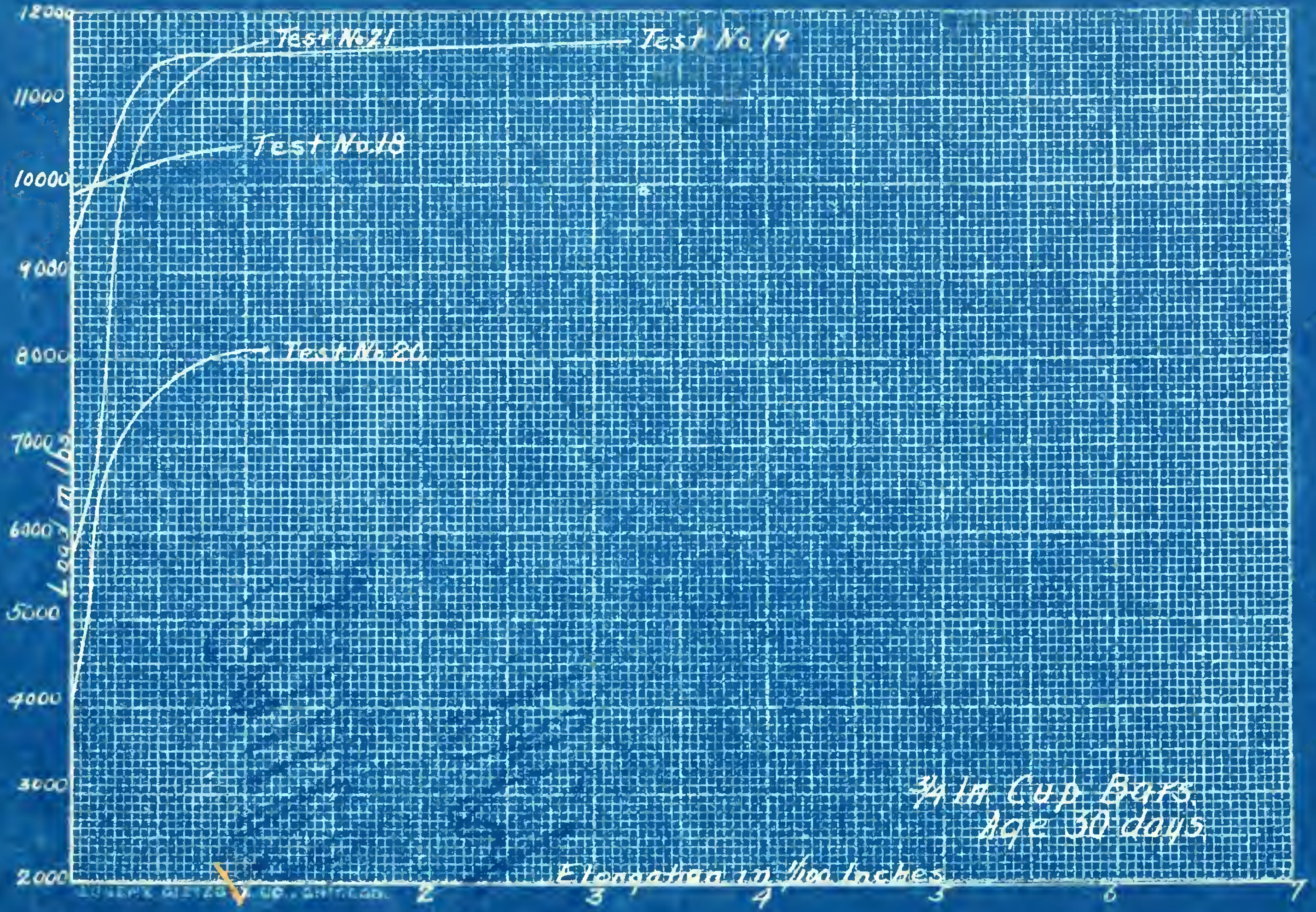
Test No.	18	19
Age of Concrete, days	30	30
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	10430	11610
Maximum Bond, lbs. per sq. in.	289.7	322.5
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	18550	20620
Elastic Limit, lbs. per sq. in.	58760	58760
Ratio of Stress to Elastic Limit	.3157	.3509

Log of Test of Cup Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 20			Test No. 21		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5633		200	.5723	
6890	.5612	.0021	6970	.5713	0010
7800	.5578	.0055	8180	.5708	.0015
8160	.5525	.0108	8950	.5706	.0017
3630	.5070	.0563	9450	.5700	.0023
			10170	.5693	.0030
			11490	.5662	.0061
			11690	.5616	.0107
			4370	.4851	.0872

Test No.	20	21
Age of Concrete, days	30	30
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	8160	11690
Maximum Bond, lbs. per sq. in.	226.7	324.7
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	14490	20760
Elastic Limit, lbs. per sq. in.	58760	58760
Ratio of Stress to Elastic Limit	.2467	.3535


Load in lbs
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
Test No. 21
Test No. 19
Test No. 18
Test No. 20
2
3
4
5
6
7
Elongation in 1/100 inches
3/4 in. Cup Bars.
Age 30 days

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 22			Test No. 23		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5387		200	.5702	
3270	.5384	.0003	3670	.5690	.0012
3470	.5311	.0076	3150	.5574	.0128
2160	.5096	.0291	2470	.5352	.0350

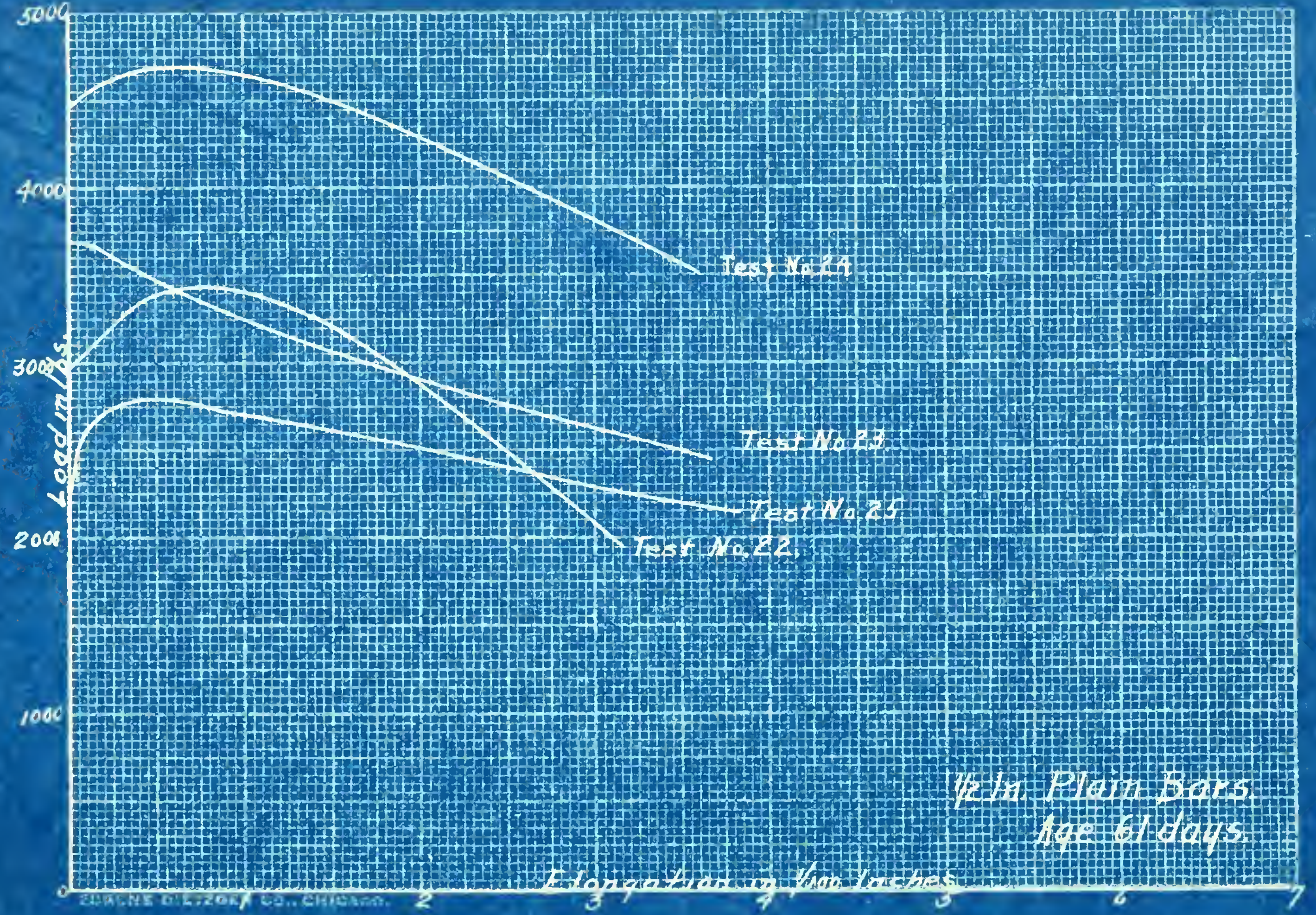
Test No.	22	23
Age of Concrete, days	61	61
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	1.57	1.57
Total Bonding Area, sq. ins.	18.85	18.85
Maximum Load, lbs.	3470	3670
Maximum Bond, lbs. per sq. in.	184.1	194.7
Area of Steel, sq. ins.	.1964	.1964
Stress in Steel, lbs. per sq. in.	17670	18690
Elastic Limit, lbs. per sq. in.	53560	53560
Ratio of Stress to Elastic Limit	.3299	.3490

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 24			Test No. 25		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.4662		200	.4860	
4500	.4660	0002	2320	.4855	.0005
4710	.4636	.0026	2800	.4843	.0017
4250	.4450	.0212	2500	.4660	.0200
3710	.4338	.0324	2150	.4475	.0385

Test No.	24	25
Age of Concrete, days	61	61
Size of Bar, ins.	½	½
Bonding Area per linear inch, sq. ins.	1.57	1.57
Total Bonding Area, sq. ins.	18.85	18.85
Maximum Load, lbs.	4710	2800
Maximum Bond, lbs. per sq. in.	249.9	148.5
Area of Steel, sq. ins.	.1964	1964
Stress in Steel, lbs. per sq. in.	23980	14260
Elastic Limit, lbs. per sq. in.	53560	53560
Ratio of Stress to Elastic Limit	.4477	.2662


5000
4000
3000
2000
1000
Load in lbs.
Test No. 24
Test No. 23
Test No. 25
Test No. 22.
2
3
4
5
6
7
Elongation in 1/100 Inches
EUGENE DIETZGEN CO., CHICAGO.
½ In. Plain Bars.
Age 61 days.

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 26			Test No. 27		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5305		200	.6616	
7350	.5273	.0032	4490	.6589	.0032
7980	.5068	.0237	5100	.6402	.0214
8210	.4909	.0396	6200	.6207	.0409
			7200	.6108	.0508
			8270	.5978	.0638
			8660	.5877	.0739

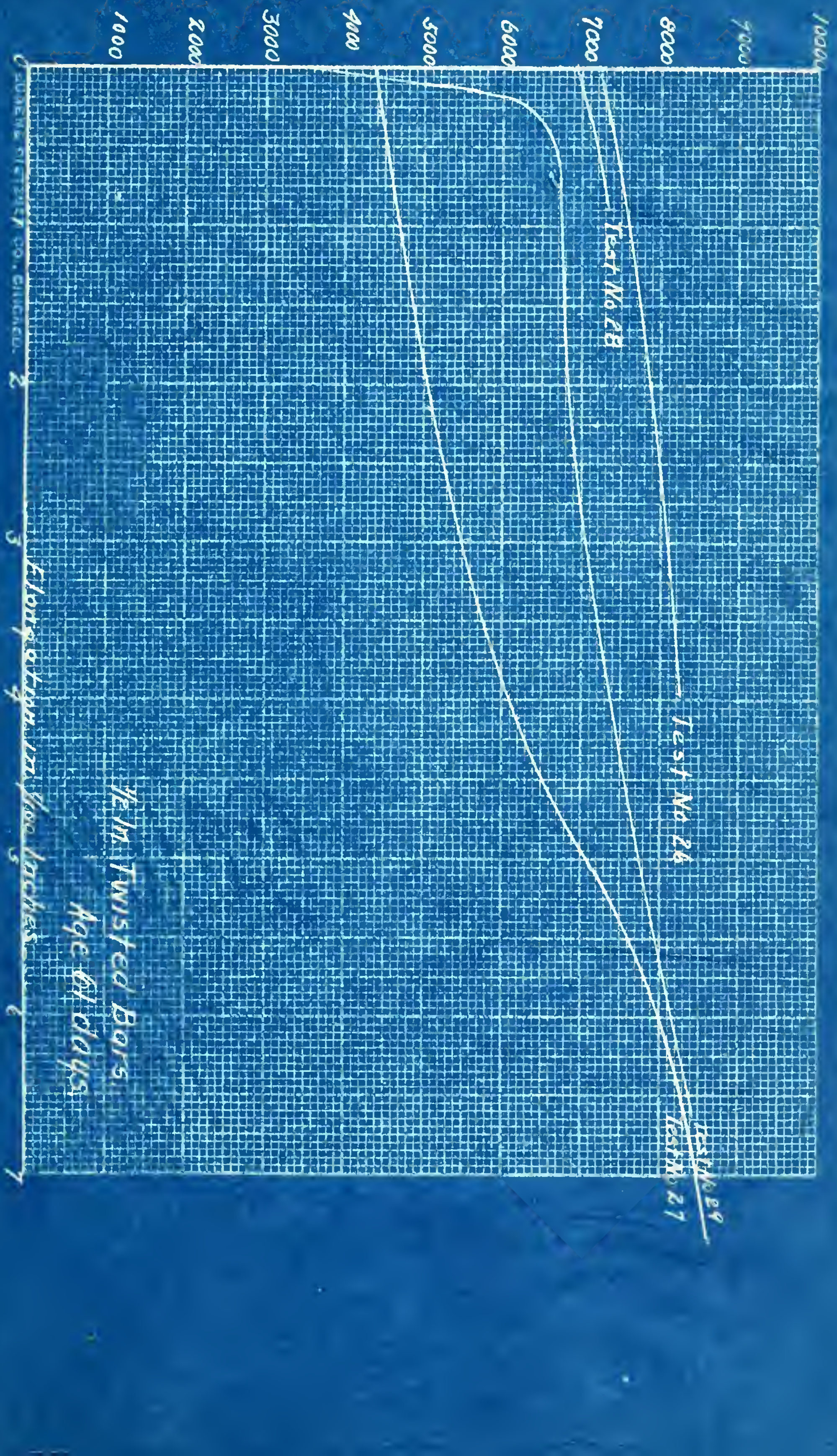
Test No.	26	27
Age of Concrete, days	61	61
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	2.00	2.00
Total Bonding Area, sq. ins.	24.00	24.00
Maximum Load, lbs.	8210	8660
Maximum Bond, lbs. per sq. in.	342.1	360.8
Area of Steel, sq. ins.	.25	.25
Stress in Steel, lbs. per sq. in.	32840	34640
Elastic Limit, lbs. per sq. in.	78400	78400
Ratio of Stress to Elastic Limit	.4189	.4418

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 28			Test No. 29		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	6142		200	5440	
7200	6110	.0032	5070	5431	.0009
7360	6055	.0087	6610	5412	.0028
			6770	5346	.0094
			7110	5104	.0336
			7390	4781	.0659

Test No.	28	29
Age of Concrete, days	61	61
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	2.00	2.00
Total Bonding Area, sq. ins.	24.00	24.00
Maximum Load, lbs.	7360	7390
Maximum Bond, lbs. per sq. in.	306.8	307.9
Area of Steel, sq. ins.	.25	.25
Stress in Steel, lbs. per sq. in.	29440	29560
Elastic Limit, lbs. per sq. in.	78400	78400
Ratio of Stress to Elastic Limit	.3755	.3770


1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
2
3
4
5
6
7
Elongation in Inches
Test No 28
Test No 26
Test No 29
Test No 27
½ In Twisted Bars
Age 61 days

Log of Test of Cup Bars

Thesis of H. R. Webb and S. H. Wilsey"
Armour Institute of Technology

Test No. 30			Test No. 31		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5647		200	5616	
2160	.5592	.0055	4940	5587	0029
3450	.5431	.0216	5600	5580	0036
4520	.5344	.0303	6550	5562	0059
5490	.5252	.0395	7800	5502	.0164
6370	.5043	.0604	8600	5437	0179
6680	.4898	.0749	9300	5374	0242
			9870	5345	0271
			10660	5169	0447
			11200	4990	0646
			11200	4597	.1019
			Bond completely broken before Concrete split.		

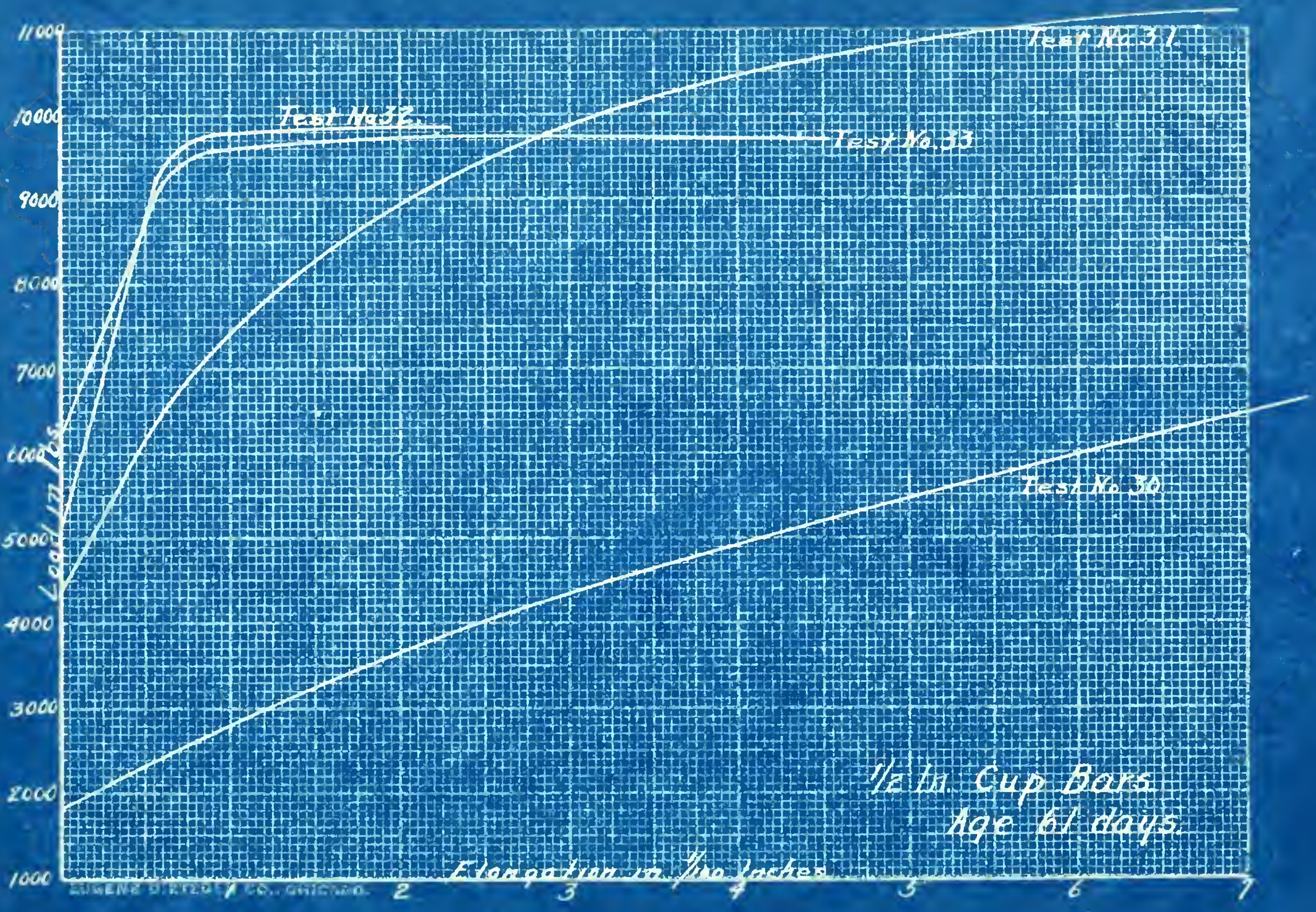
Test No.	30	31
Age of Concrete, days	61	61
Size of Bar, ins.	½	½
Bonding Area per linear inch, sq. ins.	2.00	2.00
Total Bonding Area, sq. ins.	24.00	24.00
Maximum Load, lbs.	6680	11200
Maximum Bond, lbs. per sq. in.	278.4	466.7
Area of Steel, sq. ins.	.25	.25
Stress in Steel, lbs. per sq. in.	26720	44800
Elastic Limit, lbs. per sq. in.	70000	70000
Ratio of Stress to Elastic Limit	.3817	.6400

Log of Test of Cup Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 32			Test No. 33		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5984		200	.5710	
7000	.5966	.0018	5350	.5706	.0004
8650	.5939	.0045	5870	.5700	.0010
9620	.5911	.0073	8540	.5672	.0038
9730	.5762	.0222	9490	.5640	.0070
			9740	.5274	.0436

Test No.	32	33
Age of Concrete, days	61	61
Size of Bar, ins.	½	½
Bonding Area per linear inch, sq. ins.	2.00	2.00
Total Bonding Area, sq. ins.	24.00	24.00
Maximum Load, lbs.	9730	9740
Maximum Bond, lbs. per sq. in.	405.4	405.8
Area of Steel, sq. ins.	.25	.25
Stress in Steel, lbs. per sq. in.	38920	38960
Elastic Limit, lbs. per sq. in.	70000	70000
Ratio of Stress to Elastic Limit	.5560	.5565


1/2 In. Cup Bars
Age 61 days
Load in lbs.
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
Elongation in 1/10 Inches
2
3
4
5
6
7
Test No. 31.
Test No. 32.
Test No. 33
Test No. 30
EUGENE DIETZGEN CO. CHICAGO.

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 34			Test No. 35		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	5410		200	.4217	
4290	.5391	.0019	6200	.4201	.0016
2980	.5150	.0260	4900	.4001	.0206
2620	.5015	.0395	3950	.3808	.0409

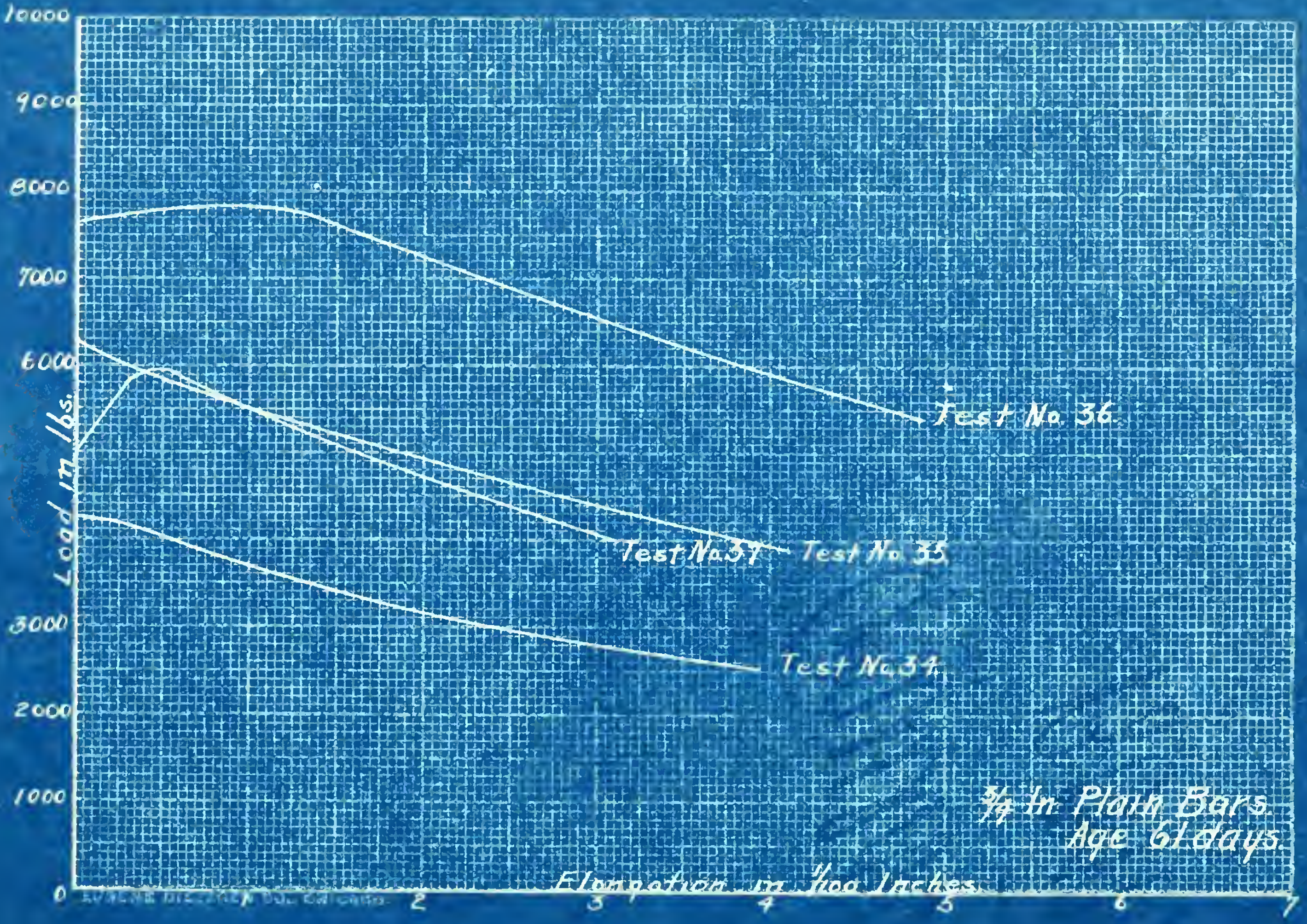
Test No.	34	35
Age of Concrete, days	61	61
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	2.356	2.356
Total Bonding Area, sq. ins.	28.274	28.274
Maximum Load, lbs.	4290	6200
Maximum Bond, lbs. per sq. in.	151.8	219.4
Area of Steel, sq. ins.	.4418	.4418
Stress in Steel, lbs. per sq. in.	9710	14030
Elastic Limit, lbs. per sq. in.	66230	66230
Ratio of Stress to Elastic Limit	.1466	.2118

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 36			Test No. 37		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.4721		200	.5779	
7700	.4698	.0023	5490	.5763	.0016
7850	.4605	.0116	6000	.5743	.0036
6190	.4411	.0310	5070	.5656	.0123
5470	.4240	.0481	4080	.5466	.0313

Test No.	36	37
Age of Concrete, days	61	61
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	2.356	2.356
Total Bonding Area, sq. ins.	28.274	28.274
Maximum Load, lbs.	7850	6000
Maximum Bond, lbs. per sq. in.	277.7	212.3
Area of Steel, sq. ins.	.4418	.4418
Stress in Steel, lbs. per sq. in.	17770	13580
Elastic Limit, lbs. per sq. in.	66230	66230
Ratio of Stress to Elastic Limit	.2683	.2050


Load in lbs.
0
1000
2000
3000
6000
7000
8000
9000
10000
Elongation in 1/100 Inches
2
3
4
5
6
7
Test No. 36
Test No. 37
Test No. 35
Test No. 34
3/4 In Plain Bars.
Age 61 days.

Log of Test of Twisted Bars

Thesis of A. R. Wahl and S. H. Wilsey
Armour Institute of Technology

Test No. 38			Test No. 39		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.4588		200	.5813	
10990	.4575	.0013	10240	.5728	.0085

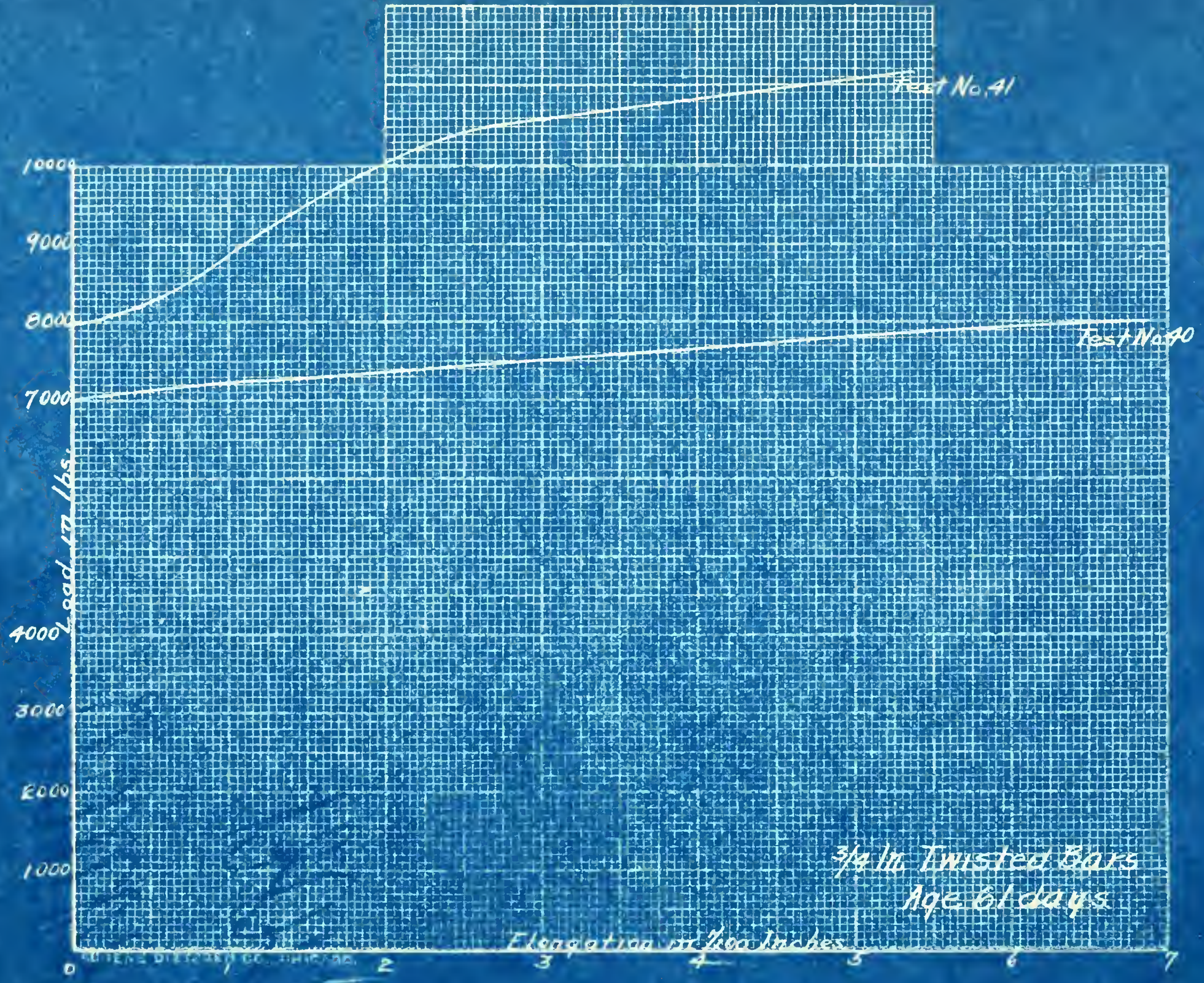
Test No.	38	39
Age of Concrete, days	61	61
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	10990	10240
Maximum Bond, lbs. per sq. in.	305.6	284.5
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	19540	18200
Elastic Limit, lbs. per sq. in.	64000	64000
Ratio of Stress to Elastic Limit	.3053	.2844

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 40			Test No. 41		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5694		200	.5840	
7040	.5678	.0016	8070	.5819	0021
7180	.5629	.0065	8470	.5766	0074
7570	.5343	.0351	8970	.5737	0103
7880	.5126	.0568	10040	.5599	0241
8000	.5007	.0687	10660	.5506	0336
			1170	.5302	0538

Test No.	40	41
Age of Concrete, days	61	61
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	8000	11170
Maximum Bond, lbs. per sq. in.	222.2	310.3
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	14220	19860
Elastic Limit, lbs. per sq. in.	64000	64000
Ratio of Stress to Elastic Limit	.2222	.3103


Test No. 41
Test No. 40
3/4 In. Twisted Bars
Age 61 days
Load in lbs.
1000
2000
3000
4000
7000
8000
9000
10000
Elongation in 1/100 Inches
0
1
2
3
4
5
6
7
EUGENE DIETZGEN CO. CHICAGO

Log of Test of Cup Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 42			Test No. 43		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	5719		200	.5665	
4330	5695	.0024	10000	.5655	.0010
3360	5642	.0057	11170	.5639	.0016
			12720	.5580	.0085

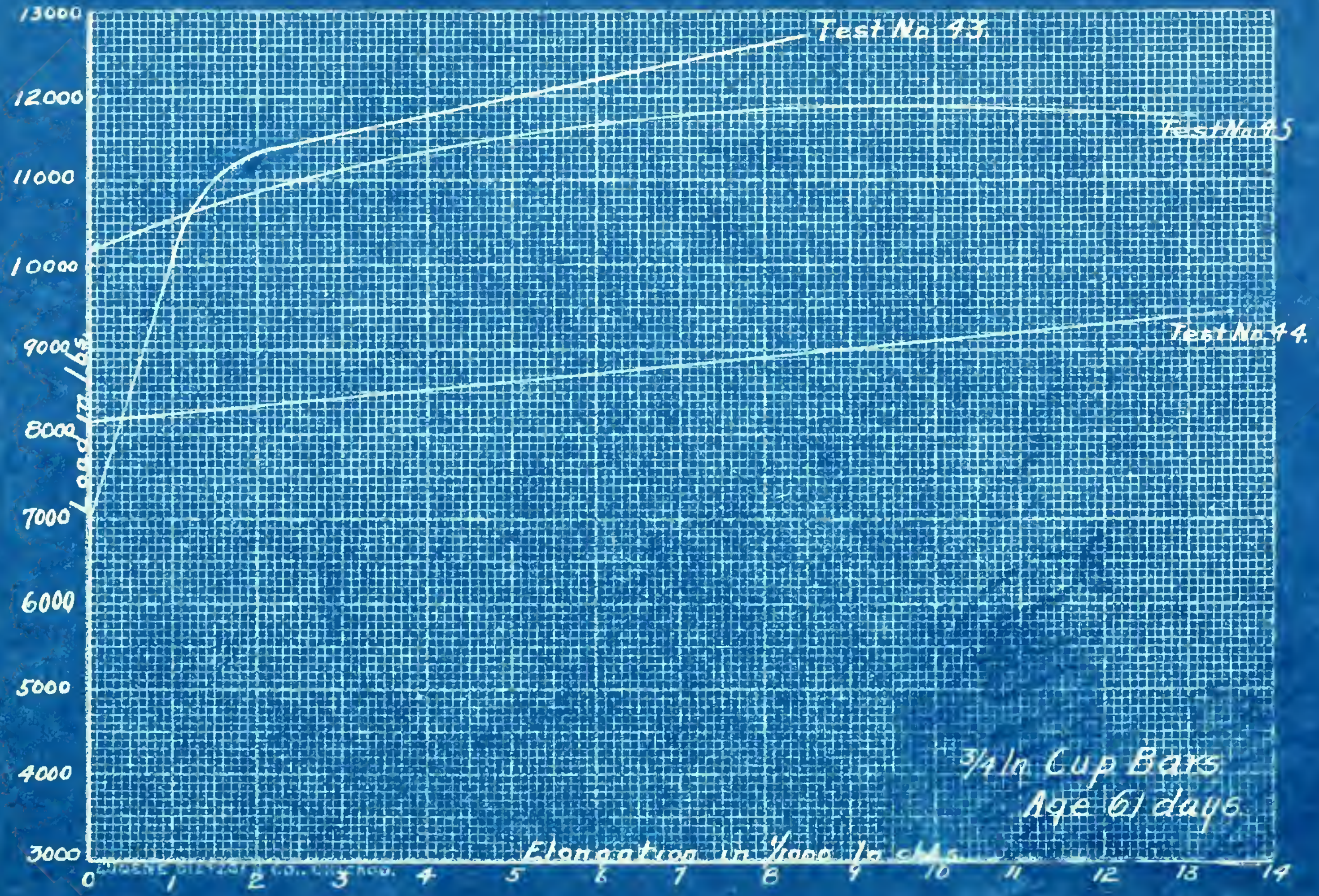
Test No.	42	43
Age of Concrete, days	61	61
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	4330	12720
Maximum Bond, lbs. per sq. in.	120.3	353.4
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	7690	22590
Elastic Limit, lbs. per sq. in.	58760	58760
Ratio of Stress to Elastic Limit	.1309	.3845

Log of Test of Cup Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 44			Test No. 45		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5709		200	.5477	
8700	.5650	.0059	10940	.5453	.0024
9450	.5574	.0135	11660	.5417	.0060
			11760	.5347	.0130

Test No.	44	45
Age of Concrete, days	61	61
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	9450	11760
Maximum Bond, lbs. per sq. in.	262.5	326.7
Area of Steel, sq. ins.	.5625	5625
Stress in Steel, lbs. per sq. in.	16780	20890
Elastic Limit, lbs. per sq. in.	58760	58760
Ratio of Stress to Elastic Limit	.2856	.3555



3/4 In Cup Bars
Age 61 days

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 46			Test No. 47		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5975		200	.4250	
2660	.5960	.0015	3090	.4246	.0004
2340	.5802	.0173	3440	.4219	.0031
1800	.5740	.0235	2670	.4091	.0159
1400	.5523	.0452	2260	.3941	.0309
1270	.5409	.0566	1850	.3728	.0522
			1430	.3130	.1120

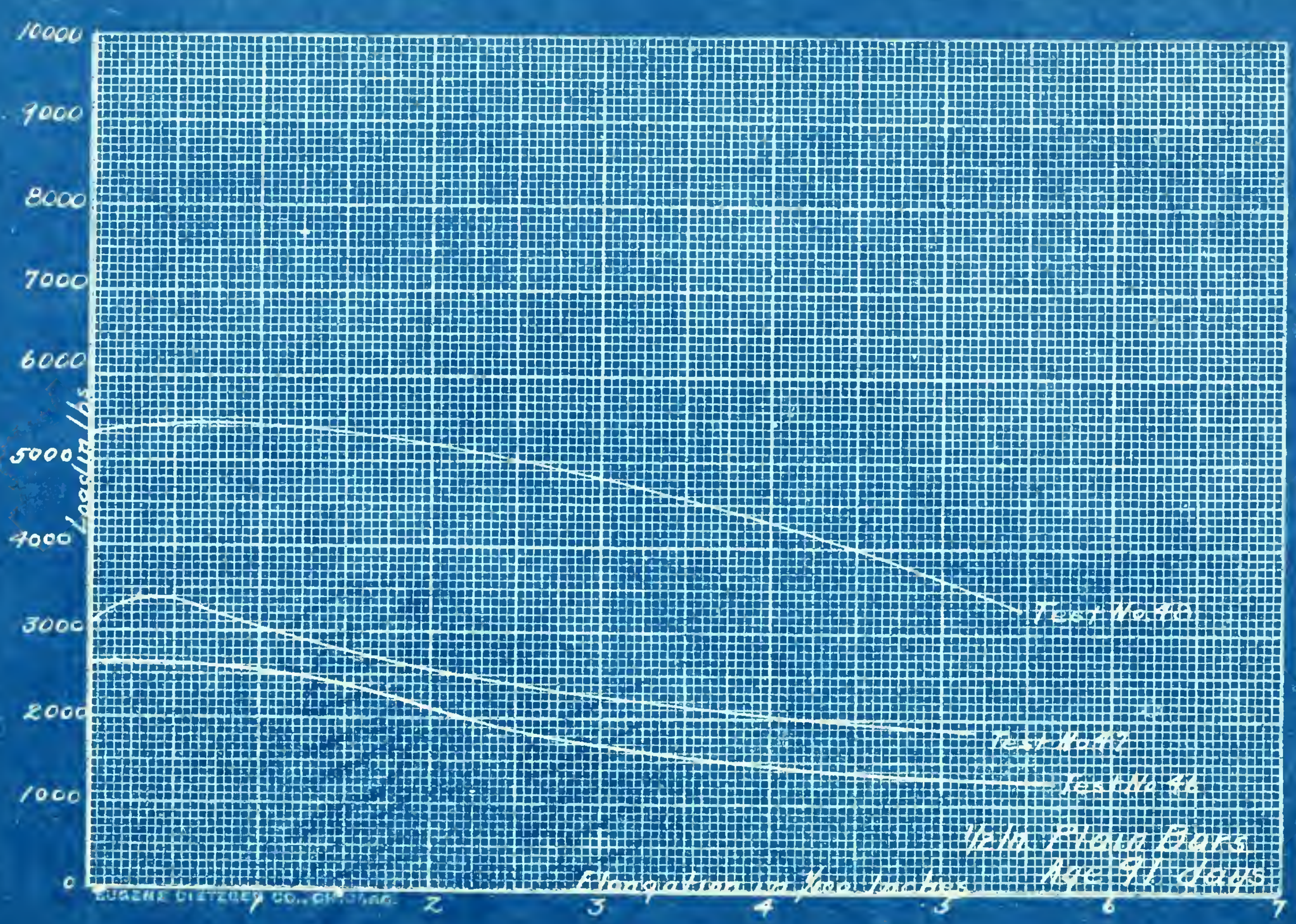
Test No.	46	47
Age of Concrete, days	91	91
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	1.57	1.57
Total Bonding Area, sq. ins.	18.85	18.85
Maximum Load, lbs.	2660	3440
Maximum Bond, lbs. per sq. in.	141.1	182.5
Area of Steel, sq. ins.	.1964	.1964
Stress in Steel, lbs. per sq. in.	13550	17520
Elastic Limit, lbs. per sq. in.	53560	53560
Ratio of Stress to Elastic Limit	.2530	.3267

Log of Test of Plain Bars

Thesis of A. R. Webb and G. H. Wilsey
Armour Institute of Technology

Test No. 48			Test No.		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	5786				
5310	5780	0006			
5470	5720	0066			
3290	5241	0545			
2560	4749	.1037			

Test No.	48	
Age of Concrete, days	91	
Size of Bar, ins.	1/2	
Bonding Area per linear inch, sq. ins.	1.57	
Total Bonding Area, sq. ins.	18.85	
Maximum Load, lbs.	5470	
Maximum Bond, lbs. per sq. in.	290.2	
Area of Steel, sq. ins.	.1964	
Stress in Steel, lbs. per sq. in.	27850	
Elastic Limit, lbs. per sq. in.	53560	
Ratio of Stress to Elastic Limit	.5200	



½ In. Plain Bars
Age 91 days

Log of Test of Twisted Bars

Thesis of A. R. Webb and G. H. Wilsey
Armour Institute of Technology

Test No. 49			Test No. 50		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5709		200	.6170	0
9280	.5697	.0012	8980	.6149	.0021
10260	.5683	.0026	9800	.5701	.0369
10740	.5651	.0058	10820	.5560	.0610
10750	.5562	.0147	11720	.5481	.0689
11320	.5189	.0520	12690	.5348	.0822
12150	.4896	.0813	13940	.5186	.0984
			14770	.4471	.1699

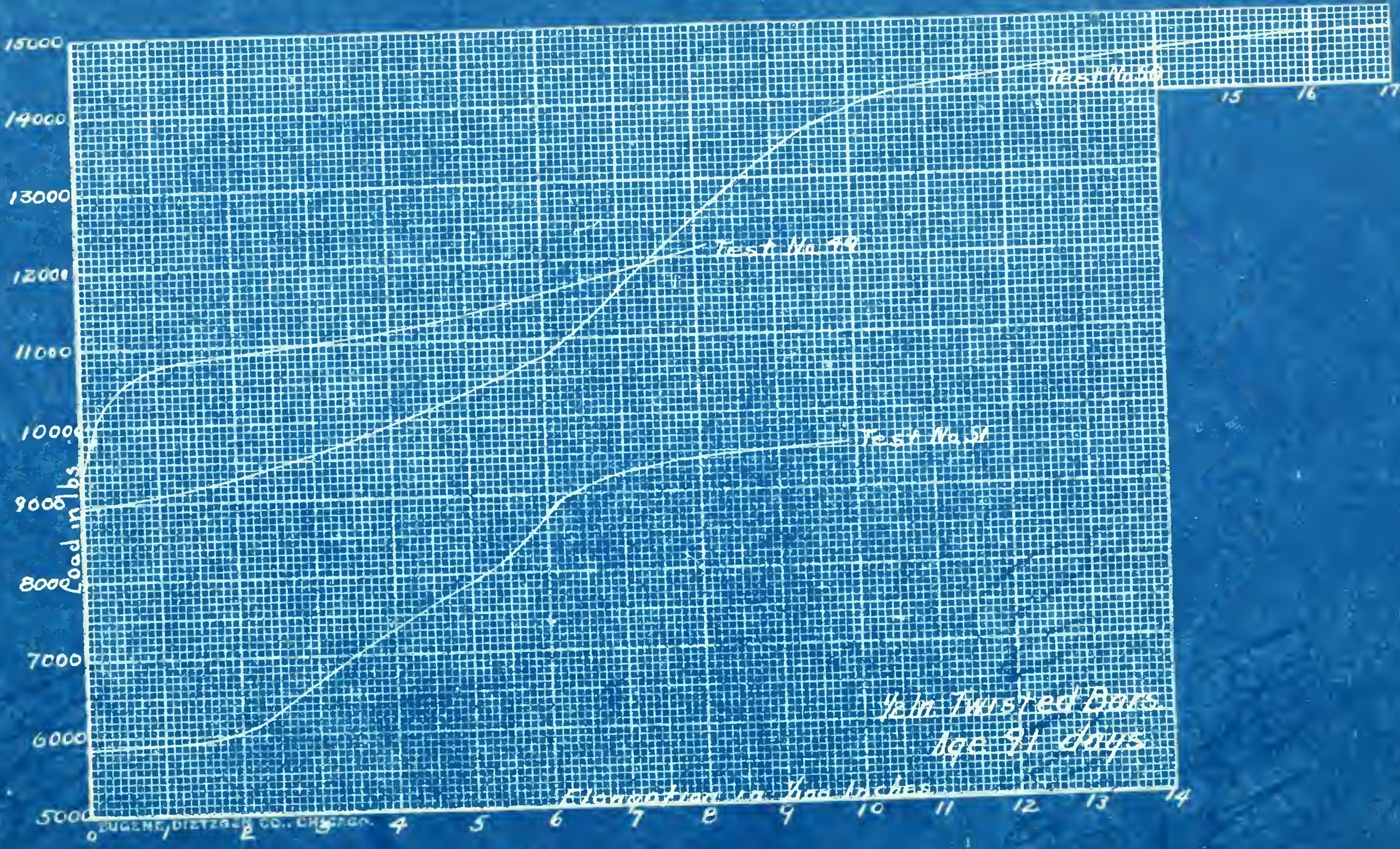
Test No.	49	50
Age of Concrete, days	91	91
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	2.00	2.00
Total Bonding Area, sq. ins.	24.00	24.00
Maximum Load, lbs.	12150	14770
Maximum Bond, lbs. per sq. in.	506.3	615.5
Area of Steel, sq. ins.	.25	.25
Stress in Steel, lbs. per sq. in.	48600	59080
Elastic Limit, lbs. per sq. in.	78400	78400
Ratio of Stress to Elastic Limit	.6199	.7536

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 51			Test No.		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5476				
5830	.5466	.0010			
5920	.5230	.0246			
7610	.5041	.0435			
8300	.4887	.0589			
9300	.4831	.0645			
9600	.4481	.0995			

Test No.	51	
Age of Concrete, days	91	
Size of Bar, ins.	1/2	
Bonding Area per linear inch, sq. ins.	2.00	
Total Bonding Area, sq. ins.	24.00	
Maximum Load, lbs.	9600	
Maximum Bond, lbs. per sq. in.	400.0	
Area of Steel, sq. ins.	.25	
Stress in Steel, lbs. per sq. in.	38400	
Elastic Limit, lbs. per sq. in.	78400	
Ratio of Stress to Elastic Limit	.4898	


15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
Load in lbs
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Elongation in [illegible] inches
Test No. 50
Test No. 49
Test No. 51
½ in. Twisted Bars
Age 91 days
EUGENE DIETZGEN CO., CHICAGO.

Log of Test of Cup Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 52			Test No. 53		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5870		200	.5964	
1530	5850	.0020	7000	.5960	.0004
4740	5825	.0045	8260	.5950	.0014
12520	5100	.0770	8900	.5940	.0024
Rod pulled gradually between 4740# and 12520# but no record made.			10450	.5920	.0044
			11570	.5902	.0062
			12570	.5860	.0104
			12950	.5834	.0130
			13390	.5811	.0153
			13450	.5800	.0164
			14000	.5790	.0174
			14850	.5683	.0281
			15700	.5600	.0364
			15860	Concrete Split.	

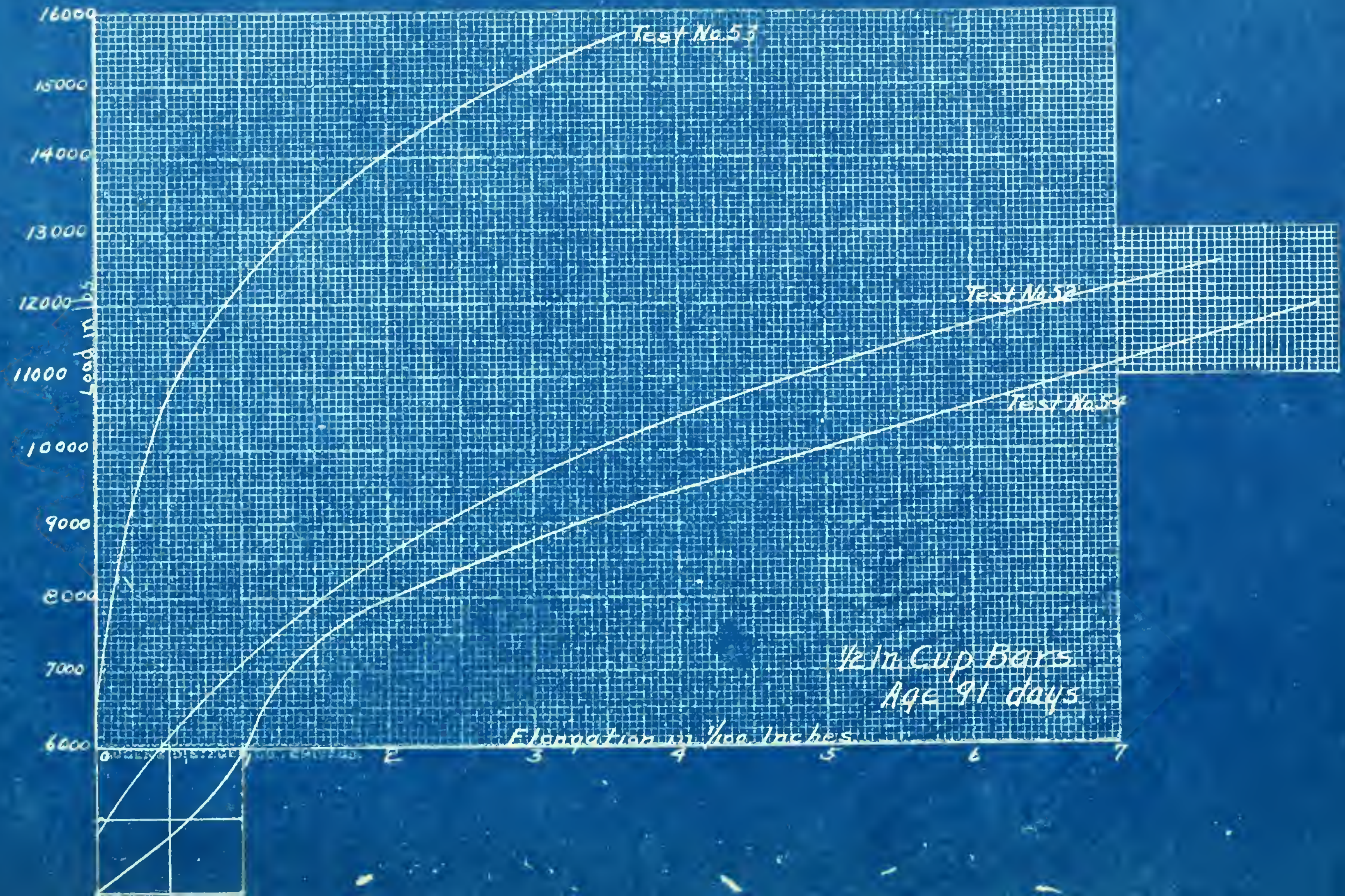
Test No.	52	53
Age of Concrete, days	91	91
Size of Bar, ins.	1/2	1/2
Bonding Area per linear inch, sq. ins.	2.00	2.00.
Total Bonding Area, sq. ins.	24.00	24.00
Maximum Load, lbs.	12520	15860
Maximum Bond, lbs. per sq. in.	521.3	660.9
Area of Steel, sq. ins.	.25	.25
Stress in Steel, lbs. per sq. in.	50080	63440
Elastic Limit, lbs. per sq. in.	70000	70000
Ratio of Stress to Elastic Limit	.7154	.9063

Log of Test of Cup Bars

Thesis of A. R. Webb and G. H. Wilsey
Armour Institute of Technology

Test No. 54			Test No.		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	5061				
4860	5010	0051			
5570	4980	0081			
6810	4941	0120			
7480	4906	0155			
7900	4879	0182			
8370	4818	0243			
9090	4731	0330			
9520	4640	0421			
10820	4420	0641			
11970	4224	0837			
12120	Concrete Split				

Test No.	54	
Age of Concrete, days	91	
Size of Bar, ins.	1/2	
Bonding Area per linear inch, sq. ins.	2.00	
Total Bonding Area, sq. ins.	24.00	
Maximum Load, lbs.	12120	
Maximum Bond, lbs. per sq. in.	505.0	
Area of Steel, sq. ins.	.25	
Stress in Steel, lbs. per sq. in.	48480	
Elastic Limit, lbs. per sq. in.	70000	
Ratio of Stress to Elastic Limit	.6926	


Load in lbs
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
Elongation in 1/100 Inches
0
2
3
4
5
6
7
Test No. 53
Test No. 52
Test No. 54
1/2 In. Cup Bars
Age 91 days

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 55			Test No. 56		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5741		200	.5753	
8180	.5733	.0008	5700	.5747	.0006
9190	.5697	.0044	6400	.5740	.0013
5240	.5456	.0285	7050	.5705	.0048
4830	.5307	.0434	5520	.5513	.0240
4420	.5132	.0609	4420	.5316	.0437

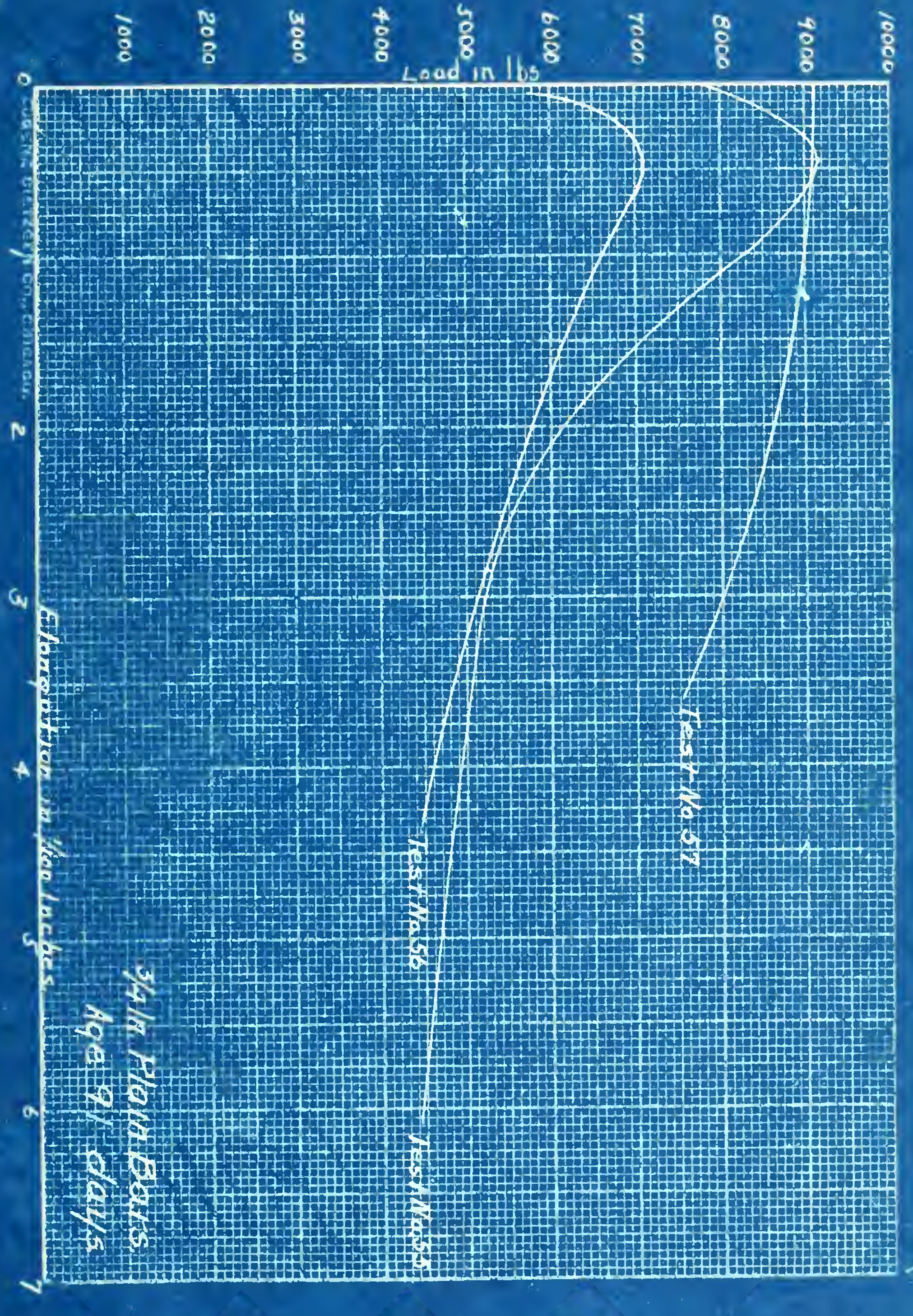
Test No.	55	56
Age of Concrete, days	91	91
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	2.356	2.356
Total Bonding Area, sq. ins.	28.274	28.274
Maximum Load, lbs.	9190	7050
Maximum Bond, lbs. per sq. in.	325.1	249.4
Area of Steel, sq. ins.	.4418	.4418
Stress in Steel, lbs. per sq. in.	20800	15960
Elastic Limit, lbs. per sq. in.	66230	66230
Ratio of Stress to Elastic Limit	.3140	.2410

Log of Test of Plain Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 57			Test No.		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5353				
9100	.5346	.0007			
9110	.5312	.0041			
8900	.5194	.0159			
7650	.4997	.0356			

Test No.	57	
Age of Concrete, days	91	
Size of Bar, ins.	3/4	
Bonding Area per linear inch, sq. ins.	2.356	
Total Bonding Area, sq. ins.	28.274	
Maximum Load, lbs.	9110	
Maximum Bond, lbs. per sq. in.	322.3	
Area of Steel, sq. ins.	.4418	
Stress in Steel, lbs. per sq. in.	20640	
Elastic Limit, lbs. per sq. in.	66230	
Ratio of Stress to Elastic Limit	.3116	


Load in lbs
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Elongation in Inches
1
2
3
4
5
6
7
Test No 57
Test No 56
Test No 55
3/4 in Plain Bars
Age 91 days

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 58			Test No. 59		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	.5654		200	.5556	
8050	.5639	.0015	6400	.5526	.0030
9310	.5621	0033	6650	.5445	.0111
9500	.5533	0121	7250	.5205	.0351
10650	.5211	0443			
11660	.4823	0831			

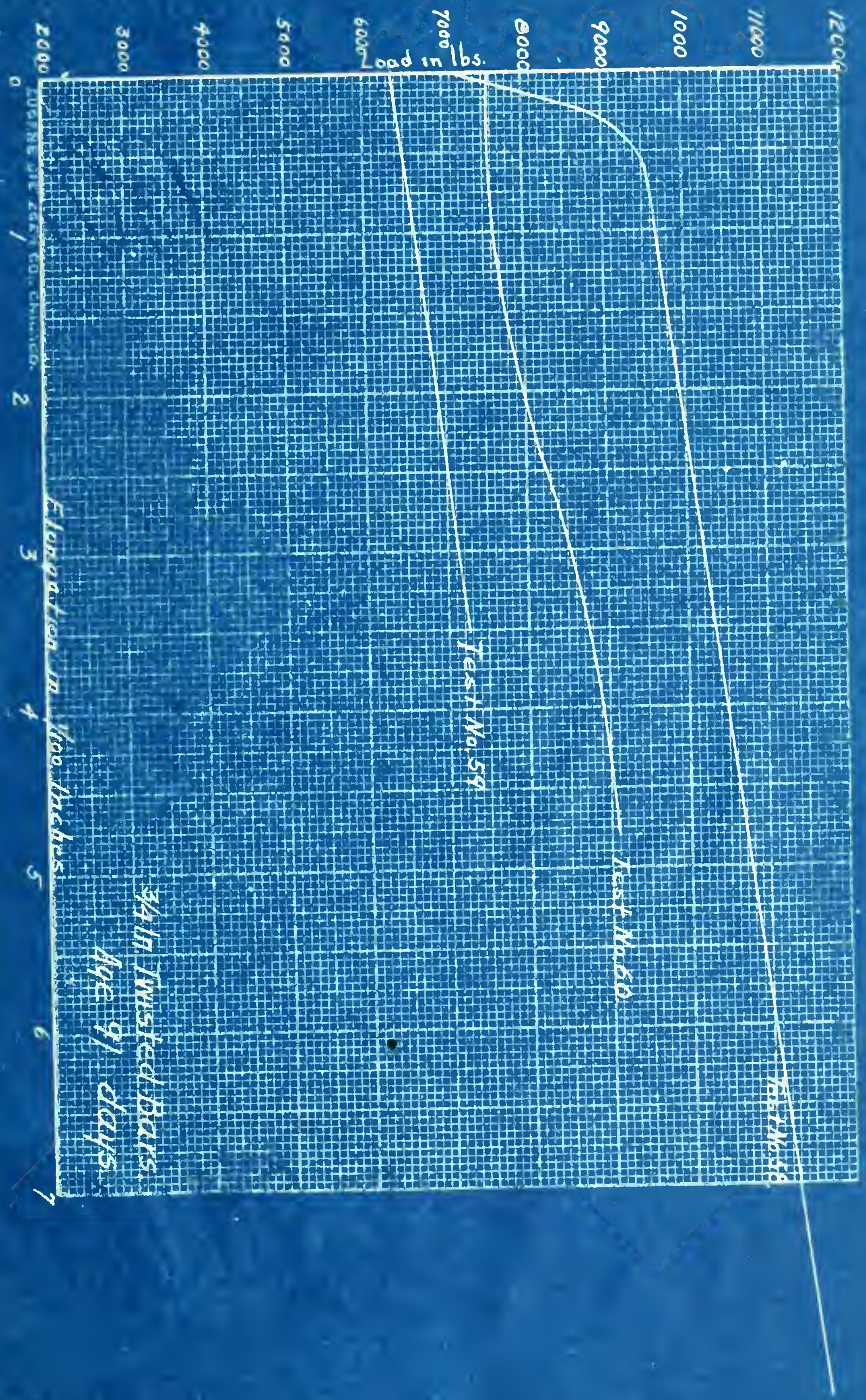
Test No.	58	59
Age of Concrete, days	91	91
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	11660	7250
Maximum Bond, lbs. per sq. in.	323.9	201.4
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	20730	12890
Elastic Limit, lbs. per sq. in.	64000	64000
Ratio of Stress to Elastic Limit	.3239	201.4

Log of Test of Twisted Bars

Thesis of A. R. Webb and S. H. Wilsey
Armour Institute of Technology

Test No. 60			Test No.		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	5531				
7520	5499	0032			
7620	5412	0119			
8700	5200	0331			
9070	5051	0480			
9220	Concrete Split				

Test No.	60	
Age of Concrete, days	91	
Size of Bar, ins.	3/4	
Bonding Area per linear inch, sq. ins.	3.00	
Total Bonding Area, sq. ins.	36.00	
Maximum Load, lbs.	9220	
Maximum Bond, lbs. per sq. in.	256.1	
Area of Steel, sq. ins.	.5625	
Stress in Steel, lbs. per sq. in.	16390	
Elastic Limit, lbs. per sq. in.	64000	
Ratio of Stress to Elastic Limit	.2561	


Load in lbs.
2000
3000
4000
5000
6000
7000
8000
9000
1000
11000
12000
0
1
2
3
4
5
6
7
Elongation in 1/100 Inches
Test No.59
Test No.60
Test No.6
3/4 in Twisted Bars.
Age 91 days.
EUGENE DIETZGEN CO. CHICAGO.

Log of Test of Cup Bars

Thesis of H. R. Webb and G. H. Wilsey
Armour Institute of Technology

Test No. 61			Test No. 62		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	5686		200	.5671	
8140	5671	0015	10460	.5647	.0024
8670	5588	0098	11460	.5607	.0064
			12110	.5558	.0113

Test No.	61	62
Age of Concrete, days	91	91
Size of Bar, ins.	3/4	3/4
Bonding Area per linear inch, sq. ins.	3.00	3.00
Total Bonding Area, sq. ins.	36.00	36.00
Maximum Load, lbs.	8670	12110
Maximum Bond, lbs. per sq. in.	240.8	336.4
Area of Steel, sq. ins.	.5625	.5625
Stress in Steel, lbs. per sq. in.	15400	21510
Elastic Limit, lbs. per sq. in.	58760	58760
Ratio of Stress to Elastic Limit	.2621	.3661

Log of Test of Cup Bars

Thesis of A. R. Webb and G. H. Wilsey
Armour Institute of Technology

Test No. 63			Test No.		
Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.	Load Lbs.	Micrometer Reading, ins.	Slip of Bar Ins.
200	5805				
7910	5791	0014			
11070	5775	0030			
12810	5763	0042			
13540	5746	0059			

Test No.	63	
Age of Concrete, days	91	
Size of Bar, ins.	3/4	
Bonding Area per linear inch, sq. ins.	3.00	
Total Bonding Area, sq. ins.	36.00	
Maximum Load, lbs.	13540	
Maximum Bond, lbs. per sq. in.	376.1	
Area of Steel, sq. ins.	.5625	
Stress in Steel, lbs. per sq. in.	24050	
Elastic Limit, lbs. per sq. in.	58760	
Ratio of Stress to Elastic Limit	.4093	

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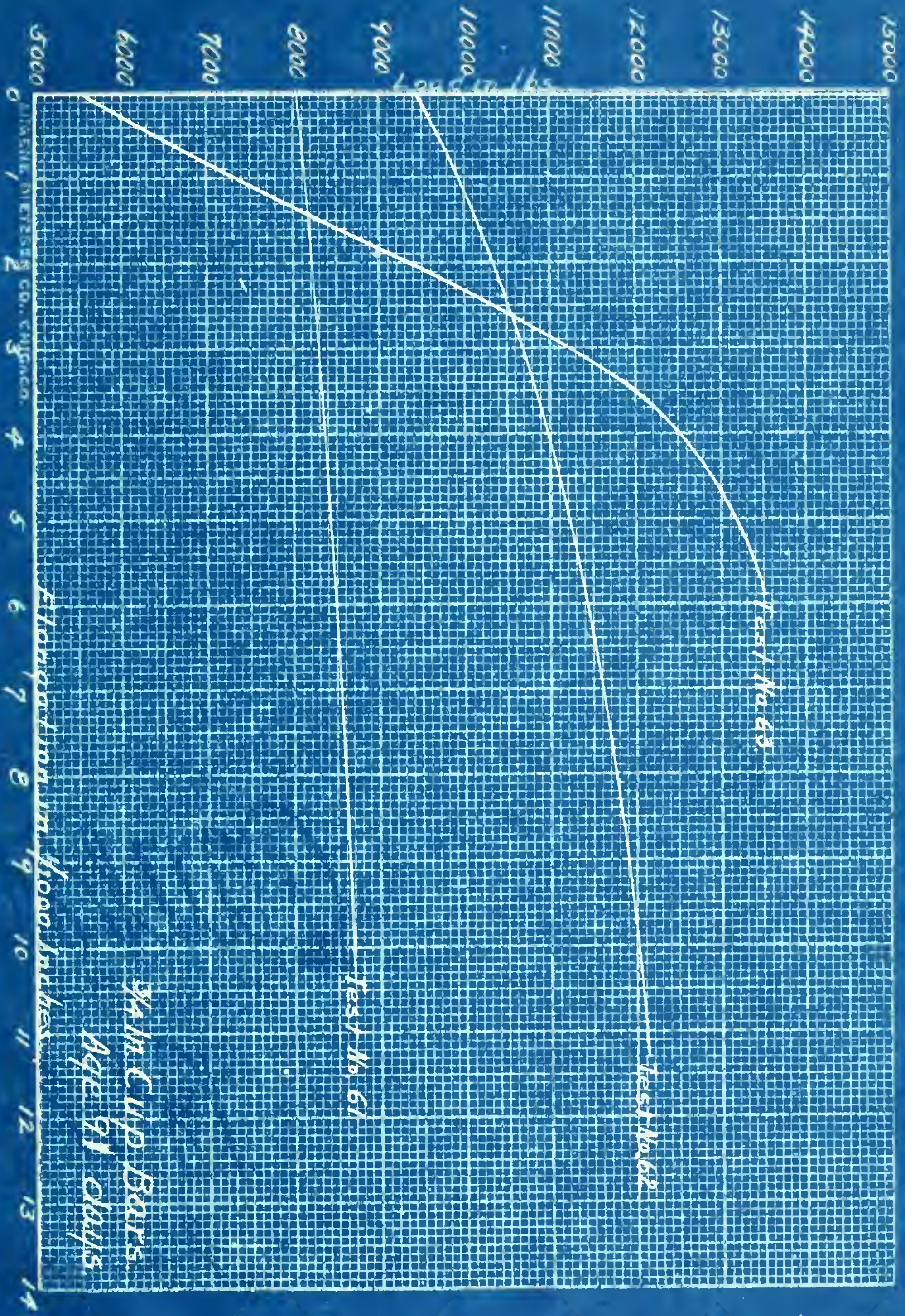
Load in lbs
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
Elongation in 1/1000 inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Test No. 63
Test No. 62
Test No. 61
3/4 in Cup Bars
Age 91 days